SR 308 MP 0.94 Big Scandia Creek (990235): Preliminary Hydraulic Design Report

JULIE HEILMAN, P.E., STATE HYDRAULIC ENGINEER
Certification FPT20-03166
Y-12554 Olympic Region GEC

PHD LEAD PROFESSIONAL ENGINEER: Chad Booth, PE, Water Resources Project Engineer
FPT20-27745 - David Evans and Associates Inc. – Olympia, WA

AUTHORING FIRM PHD QC REVIEWER(S): Greg Laird, PE, CFM
FPT20-31345 - David Evans and Associates Inc.

OLYMPIC REGION GEC FISH PASSAGE AND STREAM DESIGN ADVISOR (SDA):
Nicholas VanBuecken, PE - FPT20-08789 - Jacobs

LIST OF CONTRIBUTING ENGINEERS, GEOMORPHOLOGISTS, AND BIOLOGISTS:

Devin Maloney, LG, Geomorphologist, David Evans and Associates, Inc., Tacoma, WA (FPT20-43557)
Bryan Darby, Biologist, David Evans and Associates, Inc., Bellevue, WA (FPT20-39955)
Sulochan Dhungel, PE, Engineer, David Evans and Associates, Inc., Denver, CO (FPT20-37787)

ROLES AND RESPONSIBILITIES FOR THIS PHD

The roles and responsibilities of the key individuals in developing this Preliminary Hydraulic Design (PHD) are defined as follows for the Olympic Region GEC:

PHD Lead PE
Responsibility: Water Resources Professional Engineer in responsible charge of this Hydraulic Design Report, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices.

Authoring Firm PHD QC Reviewer(s)
Responsibility: Qualified independent individual(s) responsible for the detailed checking and reviewing of hydraulic and stream design documents prepared by the authoring firm, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices. Before submittal to the GEC, the authoring Firm Quality Control (QC) Review shall be performed in accordance with the QC methods identified in the quality assurance document Technical Verification Form (TVF). The QC methods are defined in the Olympic Region GEC Quality Management Plan (QMP) Section 5.3 and the QMP Supplement developed specifically for Y-12554 Task AC.

Olympic Region GEC Fish Passage/Stream Design Advisor
Responsibility: Water Resources Professional Engineer providing mentorship, process oversight, quality check issue resolution, and recommendations in the approach to hydraulic analysis and design performed by the **PHD Lead PE**. Before submittal of draft deliverables from the GEC to either the PHD Lead or WSDOT Headquarters, the Olympic Region GEC Fish Passage/Stream Design Advisor will review and refine GEC comments and confirm GEC comment resolution by the **PHD Lead PE**.

Americans with Disabilities Act (ADA) Information

Materials can be made available in an alternative format by emailing the WSDOT Diversity/ADA Affairs Team at wsdotada@wsdot.wa.gov or by calling toll free: 855-362-4ADA (4232). Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

Title VI Notice to Public

It is Washington State Department of Transportation (WSDOT) policy to ensure that no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO's Title VI Coordinator at 360-705-7082 or 509-324-6018.

Contents

Figures

Tables

1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 308 crossing of Big Scandia Creek at milepost (MP) 0.94 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (site identifier [ID] 990235) and has an estimated 18,202 linear feet of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing using the unconfined bridge method due to the floodplain utilization ratio exceeding 3.0.

The crossing is located in Kitsap County, 5 miles north of Silverdale, Washington, in WRIA 15. The highway runs in a southwest–northeast direction at this location and is about 1.6 miles from the outlet of Big Scandia Creek at Liberty Bay. Big Scandia Creek generally flows from north to south beginning 200 feet upstream of the SR 308 crossing. See Figure 1 for the vicinity map.

The proposed project will replace the existing 140-foot-long 72-inch diameter corrugated metal culvert with a structure designed to accommodate a minimum hydraulic width of 25 feet. The proposed structure is designed to meet the requirements of the federal injunction using the unconfined bridge design criteria as described in the 2013 WDFW Water Crossing Design Guidelines (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT Hydraulics Manual (WSDOT 2022a).

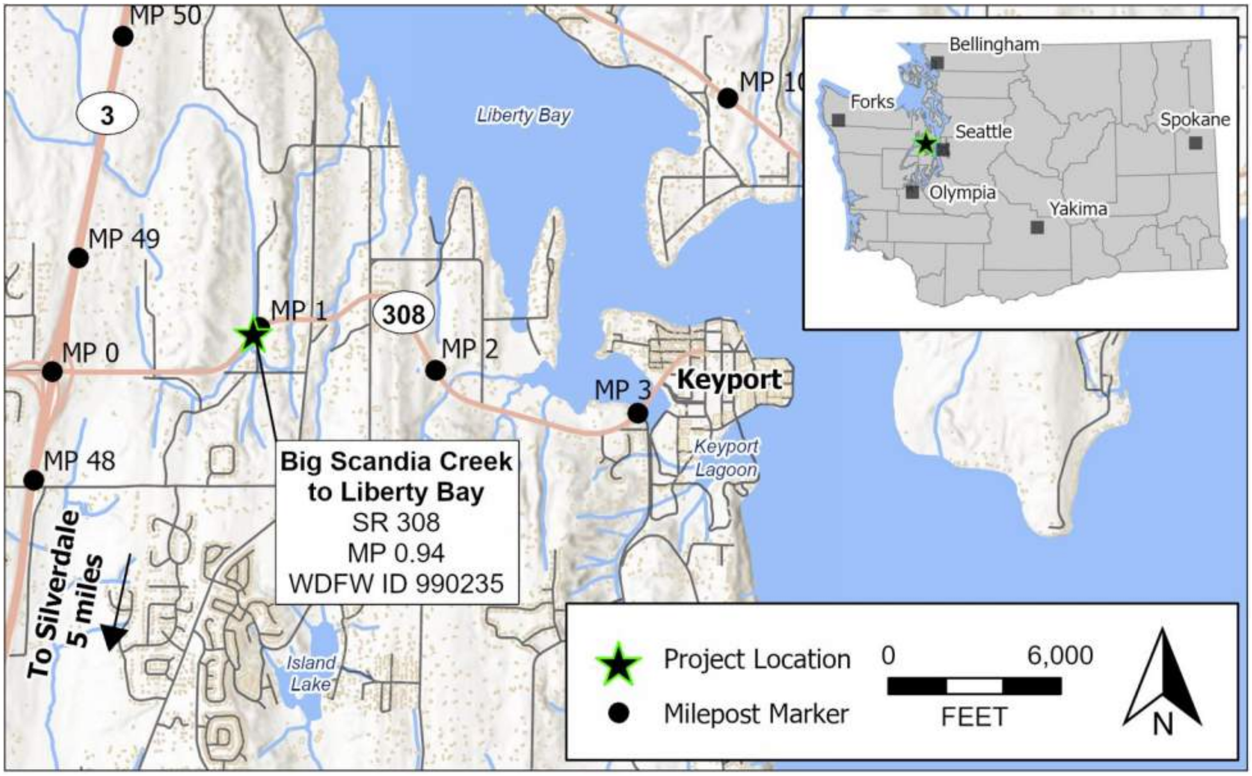


Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), WDFW, and past records such as observations, maintenance, and fish passage evaluation.

2.1 Site Description

The culvert under SR 308 at MP 0.94 (Site ID: 990235) for Big Scandia Creek is listed as a barrier due to excessive slope. The geometry and slope of the existing pipe produce excessive velocity and limited depth preventing migration upstream. The culvert drops about 1.4 feet over 141 feet, resulting in a slope of about 1 percent. In addition, there is a 3 to 4 inch drop on the downstream end of the culvert which produced a scour pool at the culvert outlet. This crossing is not listed as a Chronic Environment Deficiency (CED) or failing structure (WSDOT, 2020). The total length of habitat gain for site 990235 is 18,202 linear feet according to the WDFW fish passage & diversion screening inventory database (FPDSI, 2021) for this site.

The culvert inlet was free of debris or blockages although there were no visible signs of maintenance activity noted during the site visit. Maintenance records were requested from the WSDOT Project Engineers Office in January 2022, but no maintenance records for the culvert were available. Flooding history of the site was also not available in any relevant reports or literature, and no high-water marks were evident around the site.

2.2 Watershed and Land Cover

Big Scandia Creek at SR 308 drains approximately 1.8 square miles of watershed from unnamed three tributaries that join the primary creek channel (see Figure 2). Two of the tributaries are west of SR 3, while one of the tributaries is east of SR 3. The watershed of the contributing basin above the existing culvert was delineated using Geographic Information Systems (GIS) software and topographical data obtained from Light Detection and Ranging (LiDAR) data. The basin extends from high points along Sherman Hill Road NW to the north, Trepang Road to the west, and bluffs to the south and east.

According to the USGS National Land Cover Database for 2019 (Dewitz, 2021), the watershed contains about 57 percent forest and 35 percent developed land cover types (see Figure 3). Table 1 presents a detailed estimate of the land use percentages. The upstream area of the basin has gentle slopes where the headwater streams flow through areas with prevailing land uses such as partially developed and mixed forest types.

The maximum elevation of the basin is 460 feet in North American Vertical Datum of 1988 (NAVD 88), and the minimum elevation is 200 feet (NAVD 88) at the crossing. The overall basin has mild slopes that average less than 10 percent. The stream channel at the crossing itself has an average slope less than 1 percent. Milder slopes and runoff from developed areas upstream influence the present state of the stream, where fine sediments are abundant at the crossing.

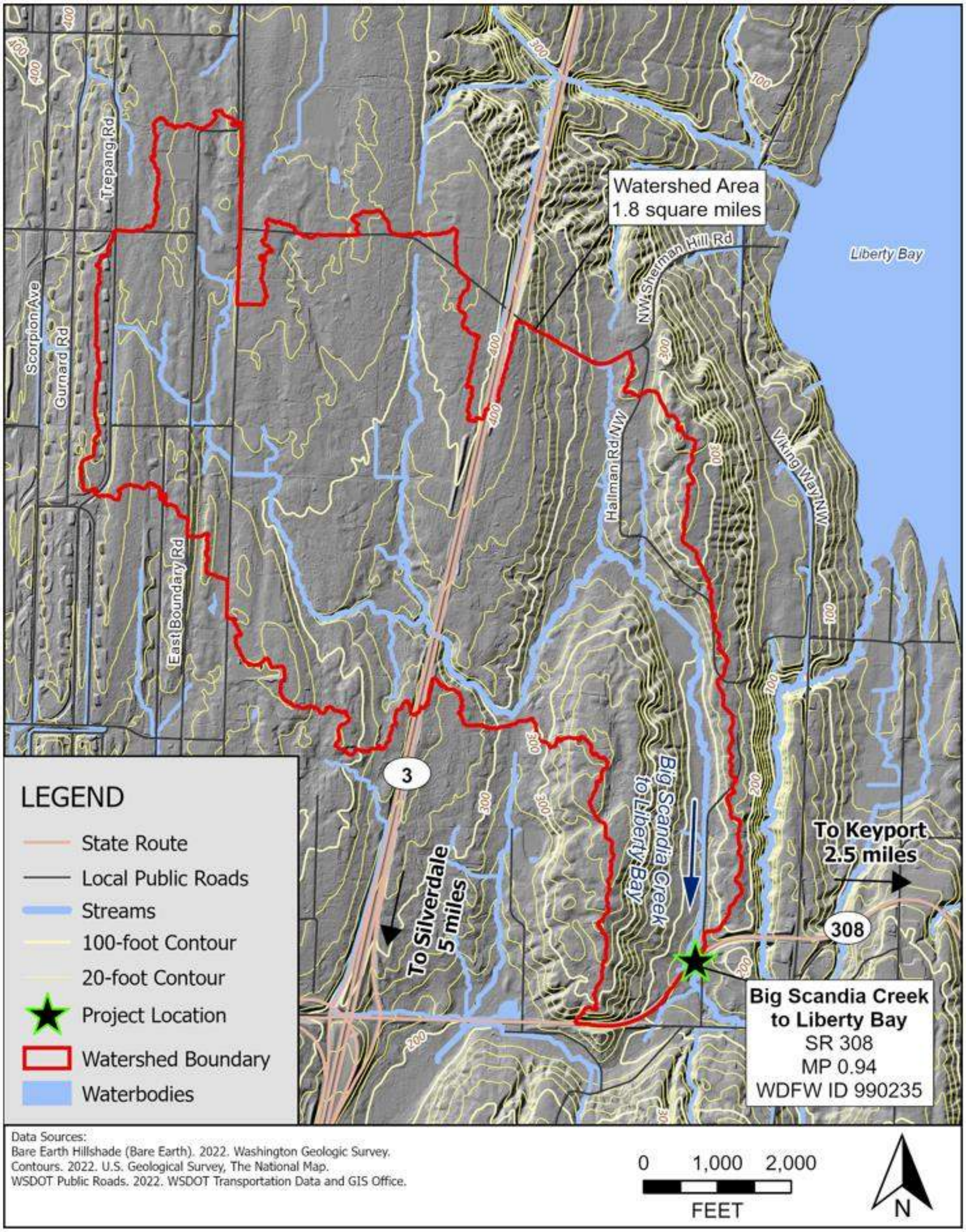


Figure 2: Watershed map

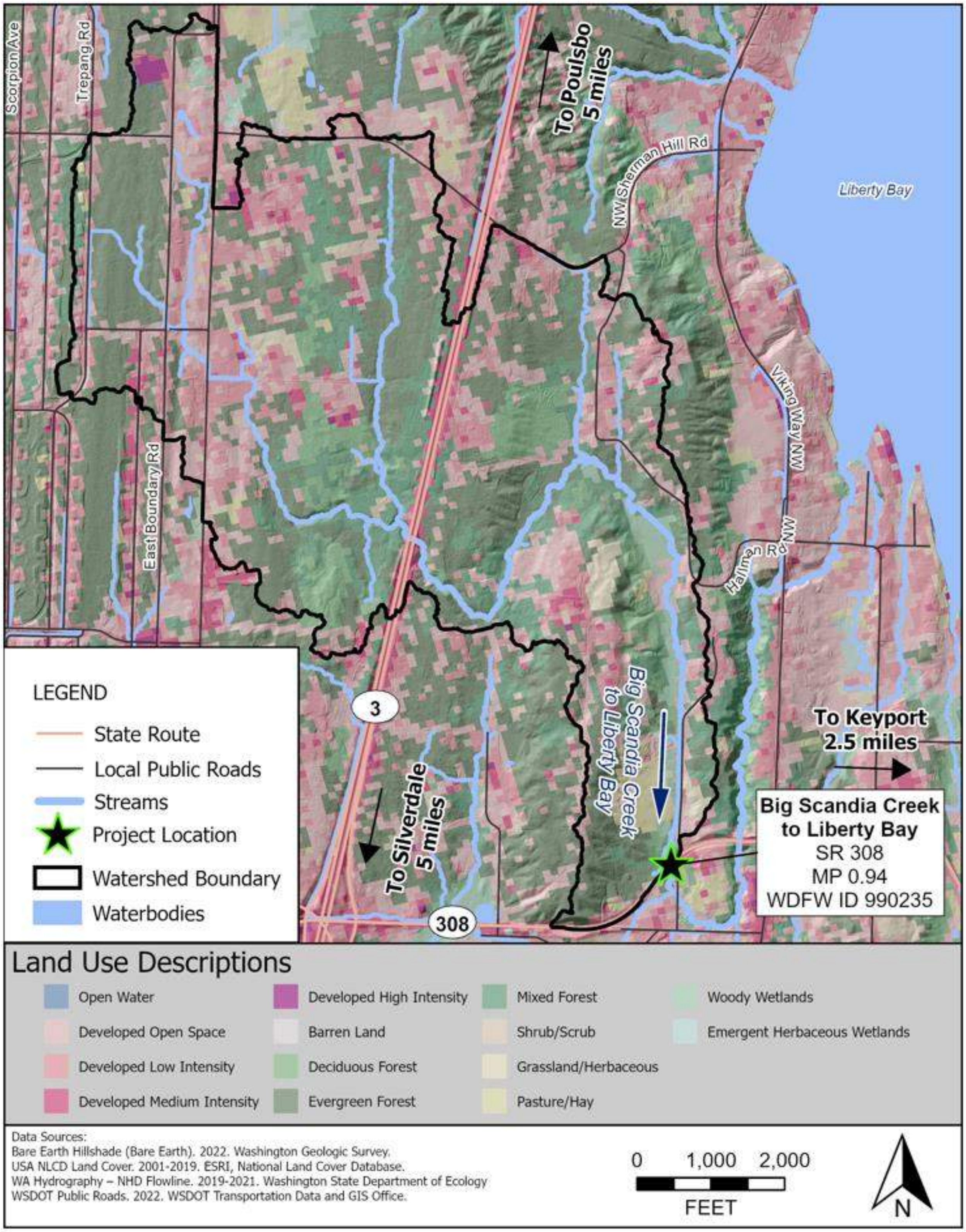


Figure 3: Land cover map

Table 1: Land cover

Land cover class	Basin coverage (percentage)
Developed, Open Space	17.9
Developed, Low Intensity	13.8
Developed, Medium Intensity	3.4
Developed, High Intensity	0.3
Deciduous Forest	7.0
Evergreen Forest	36.3
Mixed Forest	14.4
Shrub/Scrub	1.3
Herbaceous	1.6
Hay/Pasture	2.0
Woody Wetlands	1.9
Open Water	0.1

2.3 Geology and Soils

Site 990235 is located on the east side of the Kitsap Peninsula within the Puget Lowlands. The Puget Lowlands topography is shaped by glacial and non-glacial processes. Continental glaciers eroded and deposited material with each advance and retreat from the north leaving behind a glaciated surface of parallel fluted ridges with pockmarked irregular depressions (Haugerud 2009). The last continental ice sheet retreated from the Puget Lowlands approximated 16,420 calculated years before present (Porter and Swanson 1998). Pleistocene continental glacial drift (Qgic and Qpos) is the primary geologic unit deposited in the immediate project area with the upper reach of the watershed predominately Pleistocene continental glacial till (Qgt). Continental glacial drift includes cobbles, gravel, sand, and some boulders with irregular deposits of glaciolacustrine clay and till. Continental glacial till is an unsorted deposit of sand, gravel, cobbles, and some boulders suspended in a fine matrix of silt and clay. Site 990235 is located within a valley of non-glacial deposits of Quaternary alluvium (Qa) and hillslope mass wasting deposits of colluvium (Qmw) as shown in Figure 4. The alluvium consists of locally transported rounded to subrounded pebbles and sand with some cobbles, silt, and clay. Colluvium is unsorted material transported by slope failures redepositing the glacial and non-glacial deposits with the addition of local organic material (DNR Geology Portal 2022).

Landslides within the valley and urbanization of the watershed increase the sediment supply and runoff to the streams. The valley walls along the reach upstream of SR 308 are steep with mapped deposits of hillslope mass wasting on the western slope (DNR Geology Portal 2022 & Haugerud 2009). The tributary from the north, upstream of SR 3, comes from natural valleys with less anthropogenic influences, while the tributary from the west, upstream of SR 3, travels through residential neighborhoods (less porous surfaces, less seepage/infiltration, less vegetation to absorb water, etc.), thus leading to more runoff. This increase of runoff, in addition to the confinement of the stream caused by infrastructure, could have increased the rate of scour and slope failures, adding more sediment to the main reach. Downstream of SR 3, the stream goes through hillslopes and landslides potentially providing more hill-cutting and sediment to the stream. Additionally, the stream at Site 990235 flows through a low gradient alluvial flat which could limit sediment transport (see Figure 5).

The United States Department of Agriculture, Natural Resources Conservation Service Soil Survey (2022) indicates that the creek flows predominately through Alderwood gravelly sandy loam in the headwater (see Figure 6). In the gullies formed during the glacial outwash period the soils consist of Kitsap and Norma Silt Loams 0.7 miles upstream of the crossing. These soils comprise approximately 5 percent of the watershed, but they dominate within the actual channel and adjacent landscape within the eroded valleys. Silt loams are primarily composed of silts, clay, and very fine sands. Consequently, these soils are rather cohesive. Alderwood gravelly sandy loam typically have moderate infiltration rates through moderately well drained soils. Kitsap and Norma Silt loams range from slow to very slow infiltration rates due to a layer that impedes the water transmission.

The WSDOT Headquarters (HQ) Geotechnical Scoping Lead provided additional geotechnical data dated September 7, 2022. The additional data included two historical geotechnical borings done at the site in 1978. The boring on the inlet side of the crossing (J-1) was drilled to a depth of 46.5 feet and encountered primarily silty sand, while the boring on the outlet side of the crossing (J-2) was drilled to a depth of 41.5 feet and encountered silty sand with varying amounts of gravel. Both borings encountered wet conditions from the ground surface. Both boring sites had ESU-4 (Engineering Stratified Unit) until a depth of about 30 feet, which was characterized by glacial deposits with fine-grained 'soft to medium stiff silt with sand' to 'medium dense sand' that is cohesionless and has a high (II) erodibility according to HEC-18. WSDOT defines an ESU as a zone of soil or rock with consistent engineering properties. This geotechnical report also included a reported unstable slope, described as a minor slope failure likely induced by a heavy rain event, at MP 2.16 on SR 308 which is about 1.2 miles from the project site.

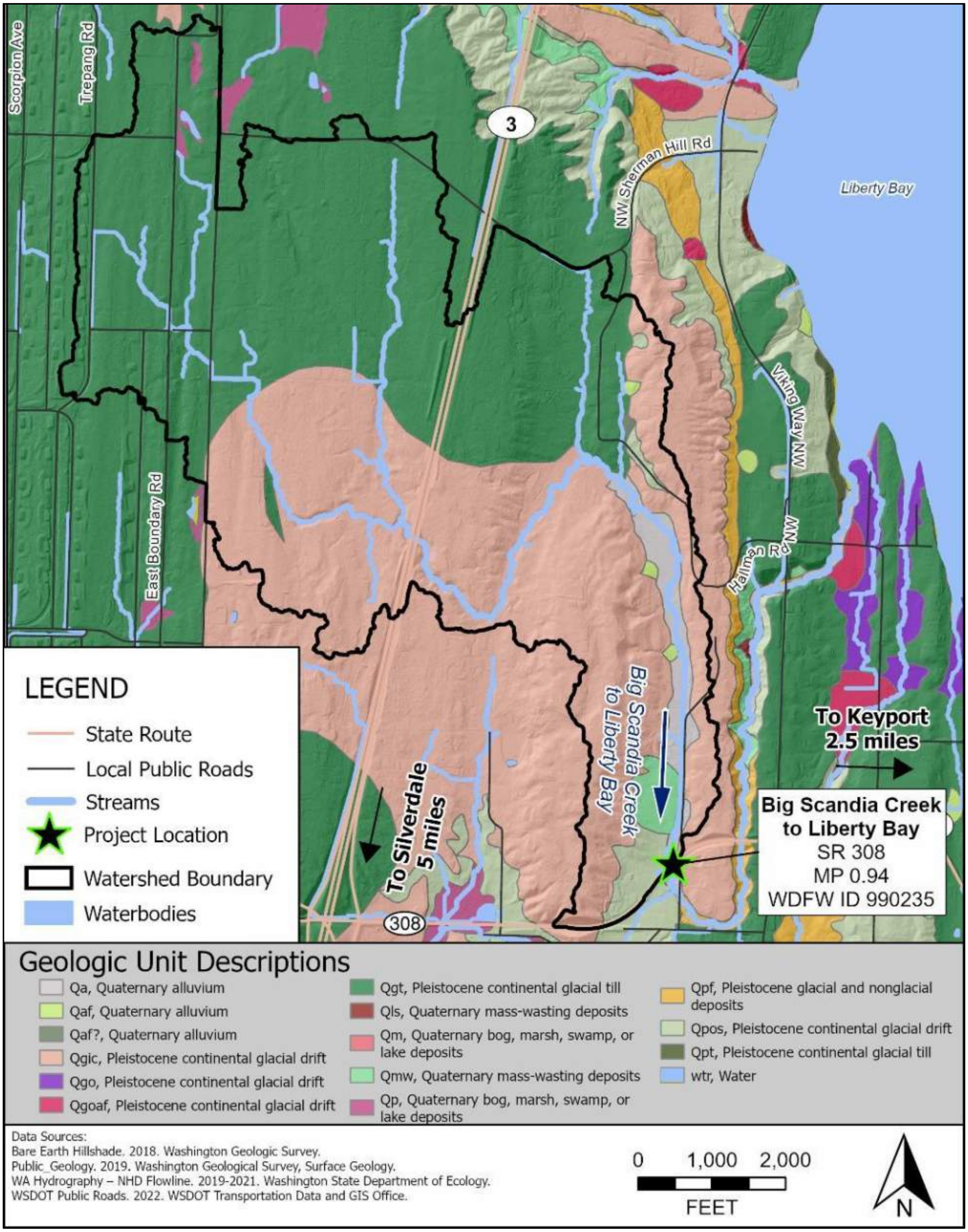


Figure 4: Geology Map

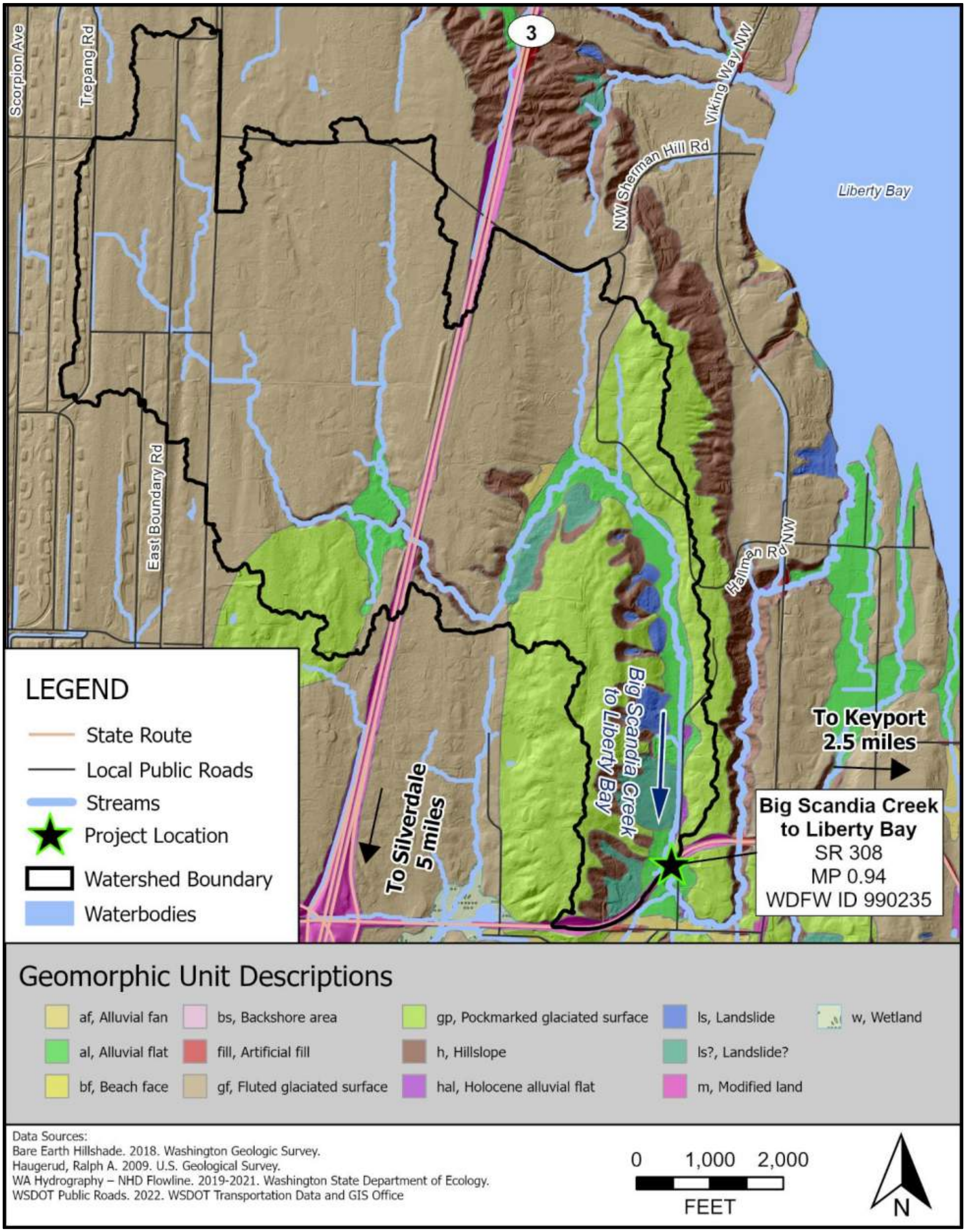


Figure 5: Geomorphic map

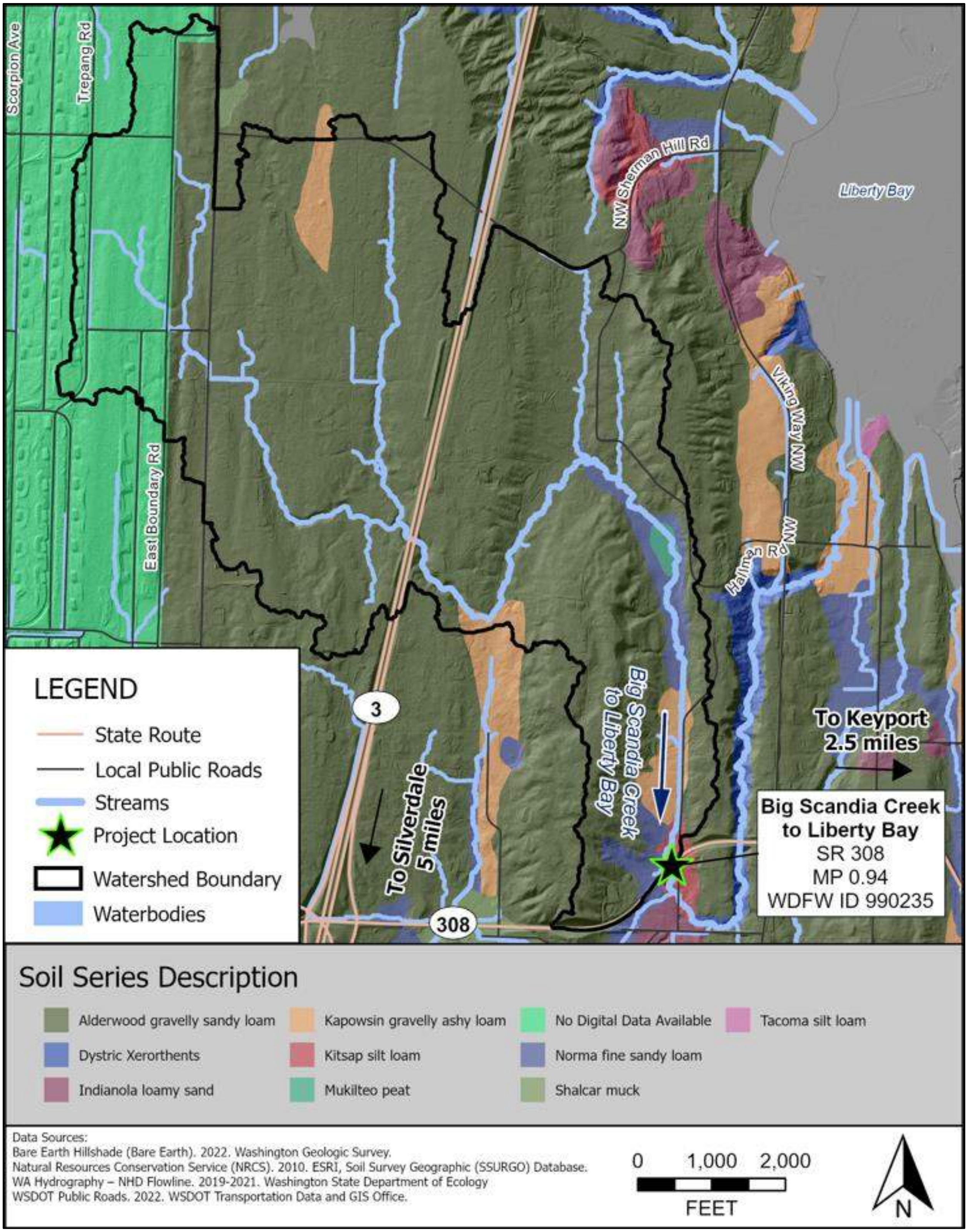


Figure 6: Soils map

2.4 Fish Presence in the Project Area

Table 2 provides a list of salmonid species documented, and potentially found in the Big Scandia Creek. Fall Chum (*Oncorhynchus keta*), Winter Steelhead (*Oncorhynchus mykiss)*, Coho (*Oncorhynchus kisutch)*, and Coastal Cutthroat Trout (*Oncorhynchus Clarki clarki)* are salmonid species that have been documented in Big Scandia Creek (SWIFD), while resident trout are presumed to live in the in Big Scandia Creek. Information was gathered from the WDFW Fish Passage and Diversion Screening Inventory Database report (WDFW, 2019).

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Fall Chum (*Oncorhynchus keta*)	Documented	WDFW	Not Listed
Winter Steelhead (*Oncorhynchus mykiss)*	Documented	WDFW	Threatened
Coho (*Oncorhynchus kisutch)*	Documented	WDFW	Not Listed
Coastal Cutthroat Trout (*Oncorhynchus Clarki clarki)*	Documented	WDFW	Not Listed
Resident Trout (*Oncorhynchus kisutch)*	Presumed	WDFW	Not Listed

2.5 Wildlife Connectivity

The 1-mile-long segment that Big Scandia Creek falls in ranked medium priority for Ecological Stewardship and medium priority for Wildlife-related Safety by WSDOT HQ Environmental Safety Office (ESO). Adjacent segments to the north and south also ranked medium.

The habitat connectivity memorandum is pending for the crossing at this time document was written, but preliminary discussions with WSDOT ESO on Tuesday July 26, 2022 indicated that a minimum Openness Index (OI) of 2.0 will be recommended for this site to accommodate the passage of deer and smaller species through the proposed structure. The OI is defined as the structure opening area (width x height) divided by the structure length. In addition to the minimum OI, 20 feet and 10 feet are generally regarded as minimums for the width and height of the structure opening for passage of deer. As stated in Section 4.2.6, a structure type will not be determined in this design phase. The minimum hydraulic width is identified in Section 4.2.2, and the vertical clearance set forth in Section 4.2.3 determines the minimum structure opening height. The resulting OI calculated from the hydraulic minimums set forth in this document, a width of 25 feet and height of 7.5 feet as measured from channel thalweg, produces an OI of 1.5 for the 127-foot-long structure. These hydraulic minimums are representative of a culvert structure. Even if a bridge structure is selected, the structure opening is not expected to increase significantly because of site constraints such as limited fill (existing fill is about 1 to 3 feet) where the roadway elevation is less than 3 feet from minimum required low chord elevation of the proposed structure.

Based on the dimensions of the minimum hydraulic opening and OI, this site is not likely to accommodate passage of deer without significant changes in roadway infrastructure. The discussions with WSDOT ESO also indicated that the MHO will not be oversized to satisfy habitat connectivity issues in this phase of the project. Any increases to the width or height of the crossing to accommodate for wildlife connectivity, if necessary, will be evaluated in the next phase of the design.

2.6 Site Assessment

2.6.1 Data Collection

WSDOT provided a topographic survey of Big Scandia Creek from approximately 150 feet downstream of SR 308 to approximately 230 feet upstream (see Appendix D) that was performed on November 23, 2021. David Evans and Associates, Inc. (DEA) visited the project site on December 1, 2021, to conduct a stream assessment and data collection needed to support development of preliminary design information. During the site visit flow in the channel was at winter baseflow levels. The existing crossing is a 140-feet-long 72-inch-diameter corrugated metal culvert.

During the site visit and stream assessment, the DEA team observed local stream and drainage basin conditions in the reach that extends about 300 feet upstream and about 300 feet downstream of the culvert inlet and outlets respectively. A summary of the site visit is provided in Appendix B. Figure 7 shows a plan view of the site and the locations where data was collected.

DEA measured six bankfull widths (BFWs) – four upstream and two downstream of the crossing. The average BFW measurement downstream of the crossing is 12.5 feet (see Section 2.7.2). DEA also performed a pebble count (PC), downstream of the crossing. The upstream reach of the crossing is influenced by backwater due to the structure. As a result, the upstream channel bed is dominated by fines, so pebble count measurements were not taken upstream. Section 2.7.3 summarizes the pebble count results.

WSDOT, WDFW staff, and Suquamish Tribal representatives visited the site on December 17, 2021. During this site visit these co-managers concurred with the reference reach location and BFW of 12.5 feet.

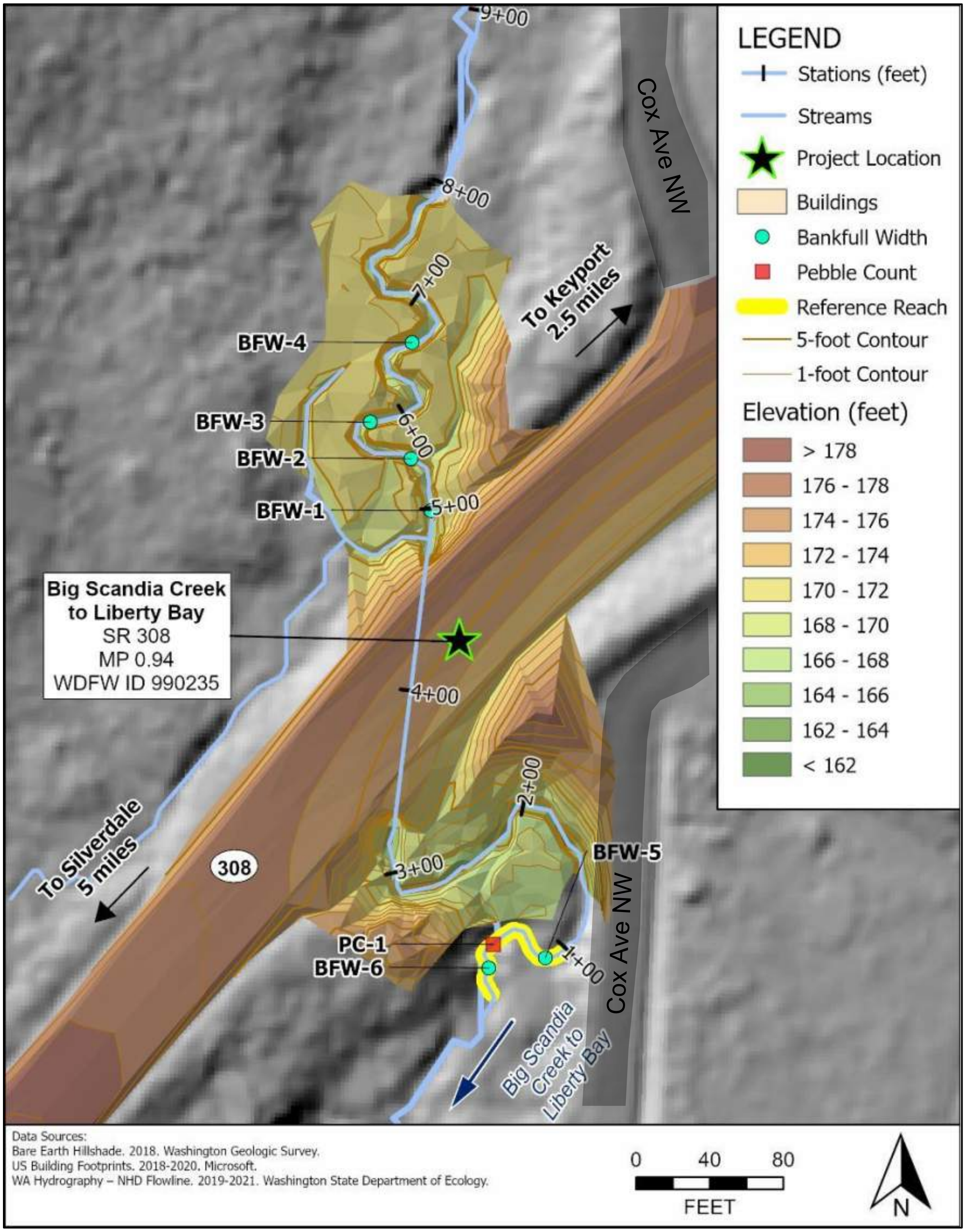


Figure 7: Reference reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

The SR 308 crossing consists of one 72-inch round corrugated metal pipe (CMP) culvert that is 140 feet long. The culvert inlet and outlet have metal flare end sections acting as wingwalls to support the transition of flow into the culvert. Visual inspection indicated that the culvert is in relatively good condition apart from minor rusting along the bottom, although it is not visible in Figure 8. There were no obvious signs of maintenance activity at the crossing.

The gradient of the culvert is 1.0 percent and has a straight alignment through the roadway fill. The culvert is skewed relative to the highway, so the length of the culvert is longer than the width of the highway (see Figure 7). The fill depth ranges from about 1 to 3 feet from the top of the culvert to the roadway pavement. As-built information and maintenance activity records for the crossing were not available when this report was written. The initial WDFW assessment stated that the culvert has a slope of 1.3 percent and is identified as a fish barrier due to excessive slope. This slope estimate differs from the recent WSDOT topographical survey, which measured the slope as 1.0 percent. However, the percent passability and barrier criteria has not changed because the culvert slope is still greater than 1 percent. Since the topographical survey was done recently and we have higher confidence in this survey, the report will use an existing culvert slope of 1.0 percent.

Figure 8: Inlet of existing 72-inch CMP (Approx STA 4+75)

According to the WDFW Fish Passage and Diversion screening inventory database report for this site (WDFW ID 990235), the drop at the culvert outlet was intentionally excavated to encourage backwater and improve passage (see Figure 9).

Figure 9: Outlet of existing culvert. Drop at the outlet and channel thalweg has caused pool to be formed (Approx STA 3+25)

Roadside ditches are the only stormwater infrastructure near or on the project site, and they discharge to Big Scandia Creek. The outfalls of the ditches do not show signs of impact on the crossing. No other nearby infrastructure was observed in the immediate vicinity of the crossing.

The assessment of the stream channel began at station 8+00, approximately 325 feet upstream of SR 308 crossing, and proceeded downstream. The stream assessment began there because it appeared beyond the influence of the SR 308 crossing. Later hydraulic modeling (see Section 5.2), showed that station 8+00 was influenced by the culvert during large flood events. The reach in this area has a relatively straight plane-bed morphology without meanders. Channel spanning logs were observed in this reach. These logs benefit the stream biota by creating shaded refuge areas (see Figure 10). Downstream of this section, between station 8+00 and 7+00, the channel has limited meander bends and mature trees grow along the banks (see Figure 11). The vegetation along this section is primarily swordfern and mid-size mature red alder (Alnus rubra) and western redcedar (Thuja plicata) trees with roots that aid in bank stability (see Figure 12). The channel slope in this reach is about 0.5 percent.

Figure 10: Straight plane-bed reach (Left) with channel spanning logs (Right) [Approx STA 8+00]

Figure 11: Mature trees providing bank stability (Approx STA 7+75)

Figure 12: Typical bank vegetation (Approx STA 7+50)

The channel section farther downstream, approximately between station 7+00 and 5+75 is highly sinuous in nature and has multiple meanders with a channel slope of approximately 0.5 percent. The stream width varies between 10 and 14 feet through this reach. Bank height in this reach is about 1 to 2 feet with limited woody material in the channel (Figure 13). Farther downstream, near station 6+60, the stream is channelized with increased bank heights (Figure 14). Large tree roots are present along the banks that help provide stabilization. Pools are present along the outside of meander bends (Figure 15). In some areas there are undercut roots which create deeper pools (Figure 16).

Figure 13: Low lying bank vegetation but limited in-channel wood (Approx STA 6+75)

Figure 14: Reach with increased bank height (Approx at STA 6+60)

Figure 15: 3-foot-deep pool on the outside the bend (Approx STA 6+25)

Figure 16: Pool formed along stream banks where trees are undercut (Approx STA 6+50)

The section of channel approximately between station 5+75 and 5+00 is immediately upstream of the culvert inlet. The 0.5 percent slope in this reach is similar to the upstream reach. Vegetation in this section is mostly small and medium alder and cedar trees (Figure 17). Some in-channel woody material was also observed in this reach. On the outside of the sharp meander bend at approximately station 5+60, a pool about 3 feet deep and undercut tree roots are present along the bank. This pool is a beneficial habitat feature providing refuge for fish (Figure 18). Further downstream, around station 5+30, the channel begins to straighten and becomes narrower (Figure 19). The bank heights are lower, and the floodplain is more accessible here. At approximately station 5+00, the velocity decreases and the stream increases in width which allows deposition of fines (Figure 20). The section of stream just upstream of culvert inlet, at approximately station 4+85, contains woody material and debris which create small pools (Figure 21). The channel upstream of the culvert also has a slope of 0.5 percent, and the vegetation along the banks is mostly ferns (Figure 22).

Figure 17: Vegetation observed along the banks (Approx STA 5+75)

Figure 18: Pool (depth about 3 feet) formed at the outer edge of meander band (Approx STA 5+60)

Figure 19: Relatively straight and narrow channel upstream of culvert inlet at BFW-2 (Approx STA 5+20)

Figure 20: Increased stream width (Left) and deposition of fines (Right) upstream of the culvert inlet (Approx STA 5+00)

Figure 21: Woody material and debris creating a pool upstream of the culvert (Approx STA 4+85)

Figure 22: View of existing condition at the SR 308 culvert inlet (Approx STA 4+75)

The culvert outlet near station 3+30 has a flared end that serves as metal wingwalls (see Figure 23). Downstream of the outlet there is a long scour pool roughly 40 feet long and 2 to 3 feet deep. At the far end of the scour pool there is a constructed weir made from woody material and quarry spalls (See Figure 24). The channel then turns sharply to the left at about 90 degrees. From here Big Scandia Creek travels along the fill slope of SR 308 for 100 feet to station 2+00. The downstream reach weaves through confining hillslopes but has little to no unconstrained meanders compared to the upstream reach. The channel slope, of 0.8 percent, in this reach is slightly steeper than upstream. The typical BFW in this reach is 8 to 9 feet with localized spots exceeding the typical widths due to small obstructions. The streambed is generally sandy with the exception of an isolated gravel bar that appears to be armored (see Figure 25).

Figure 23: Existing condition at the SR 308 culvert outlet (STA 3+30)

Figure 24: Wier downstream of culvert scour hole (STA 3+30)

Figure 25: Gravel from armored bar near STA 2+00

From station 2+00 to 1+00 the floodplain is accessible and roughly 40 feet wide with Cox Avenue restricting the east side and confining the channel width (see Figure 26 and Figure 7). The channel was likely straightened and steepened during the construction of Cox Avenue in this reach. The gradient in this reach is approximately 0.6 percent. Numerous mature western redcedar trees are present (see Figure 27). The depth of the flow during the site visit ranged from 1 to 1.5 feet.

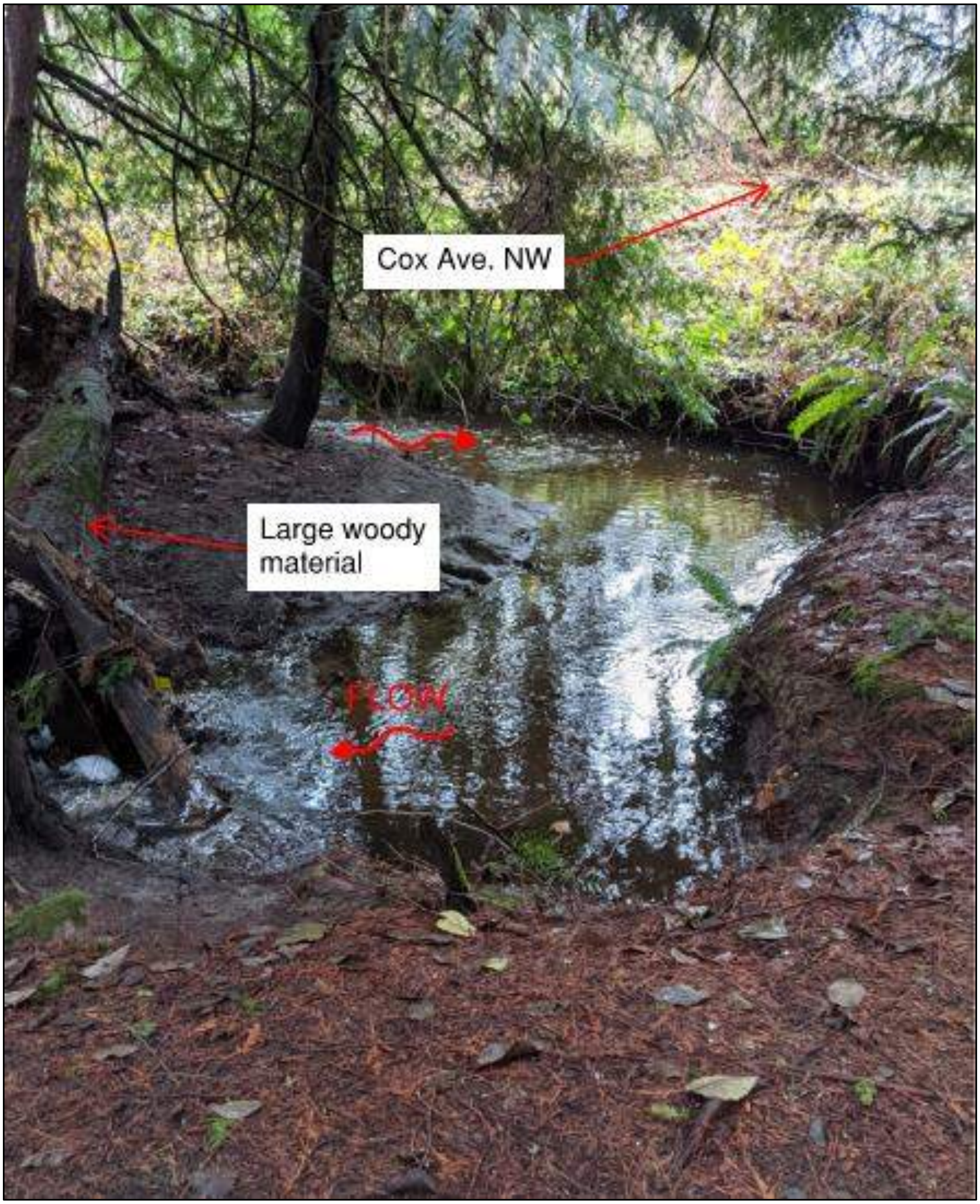


Figure 26: Channel adjacent to Cox Avenue near STA 1+50

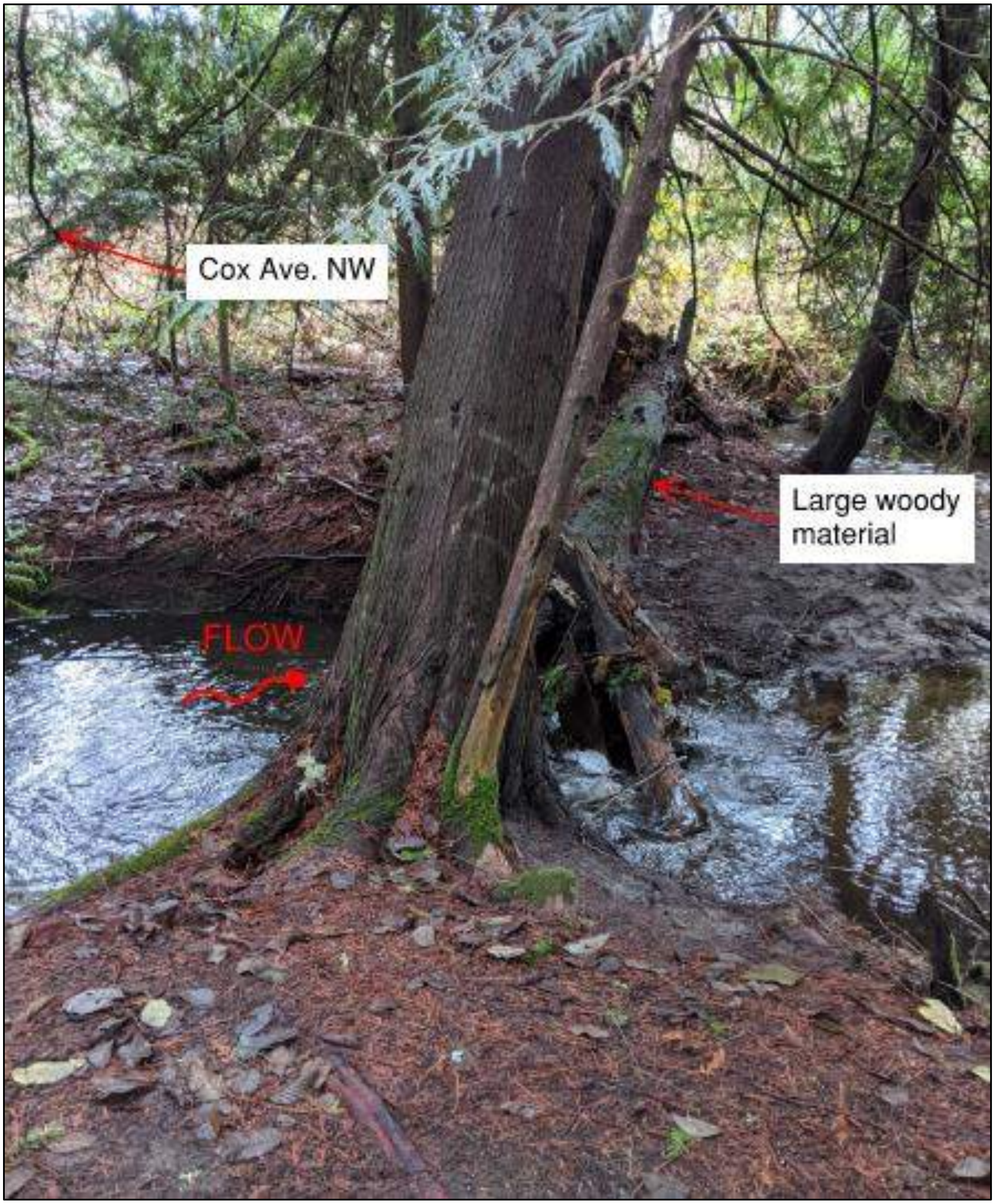


Figure 27: Large mature trees near Cox Ave (Approx STA 1+50)

From station 1+00 to 0+00 the channel is relatively undisturbed by infrastructure. This reach provided the best location for a reference reach. In this reach, the banks are stable, have light vegetation, and have wider meanders than the upstream reach. Channel material here consists of similar sandy materials that dominate the rest of the channel (see Figure 28 and Section 2.7.3). This reach has a BFW of 15 feet, which is wider than the upstream sections that are constrained by roadway fill (see Figure 27). The approximate channel gradient through this section is 0.8 percent based on LiDAR and field observations. This section of the channel is outside the surveyed area.

Figure 28: Channel within reference reach near STA 0+50

Figure 29: Looking downstream from reference reach near STA. 0+50

2.6.3 Fish Habitat Character and Quality

The SR 308 culvert for Big Scandia Creek is classified by WDFW as 33 percent passable because of slope (WDFW, 2004). Fish presence and use of the site was documented during a 2004 site visit, where adult Coho were documented downstream of the culvert. Other documented species in the creek are Fall Chum, Winter Steelhead, Coastal Cutthroat Trout, while Resident Trout are presumed to be within the creek.

Upstream of the culvert, the creek supports a large stretch of potential rearing habitat for juvenile salmonids. The area features substantial overstory cover, a slow-moving pool-riffle complex, and an abundance of large woody material (LWM), providing shelter, shade, and deeper water for juvenile salmonids. The substrate is composed of a fine silty sand mix, with an abundance of organic material. Two wetlands are present upstream of this crossing which both drain into the stream at the culvert inlet. The wetland on the left bank is scrub shrub, contains cedar and salmonberry, was inundated during the site visit, and extends several hundreds of feet into the forest. A similar wetland exists on the right bank of the creek, stretching about 200 feet into the forest, with light channelization.

Downstream of the culvert, both rearing and spawning habitat for salmonids is present. Vegetation in this section is an almost fully covered canopy of coniferous trees with almost no understory, providing the stream with excellent cover and shade year-round. Similar to upstream, a pool-riffle complex provides juvenile salmonids with adequate access to shelter and areas for migrating fish to rest. Pools range in depth from 1 to 3 feet and reach up to 10 feet in length. The flow in this section moves slightly faster than upstream. Spawning gravels and pebbles are present approximately 100 feet downstream of the culvert, though most of the stream is made up of sands and fines. Minimal LWM is present in this reach, and thus the primary rearing habitat comes in the form of deeper pool refuge.

Current conditions support rearing habitat for Steelhead, Coho, and Trout remaining in the creek after hatching, both upstream and downstream of the culvert. This rearing habitat consists of pools, adequate amounts of LWM (primarily found upstream), and riparian cover. Spawning habitat, though present downstream, is not abundant and could be improved with the addition of more cobble and gravel material.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

Upstream of the culvert, the riparian area consists of a native mid-sized overstory of western redcedar (Thuja plicata), red alder (Alnus rubra) and Douglas fir (Pseudostuga menziesii), providing the stream with 85 percent cover. A moderately dense shrubby understory of Salmonberry (Rubus spectabilis) and swordfern (Polystichum munitum) provide the stream with additional coverage, though most of the stream coverage comes from cedar and alder trees near the banks. These alder and cedar trees currently provide the stream with abundant LWM and undercut roots which create opportunities for fish refuge and future recruitment of LWM due to bank erosion. Salmonberry has the potential to provide the stream with additional coverage but was recently cut back. LWM and the sinuosity of the stream provide abundant rearing habitat for juvenile Coho, Steelhead, Cutthroat, and Trout as slow-moving water, pools, and stream coverage provide shelter from predators and the environment. The December 1, 2021 site visit did not note any beaver activity or noxious weeds.

Downstream of the culvert, the riparian areas consisted of large coniferous trees and a sparce understory. Western redcedar are the primary overstory tree, but Douglas fir and a red alders contribute to the 80 percent canopy cover as well. Minimal understory vegetation is present due to the high density of coniferous trees, and only a few swordferns are present within the first few hundred feet downstream of the culvert. A few isolated pieces of LWM in the channel interact with the flow but they do not create viable fish habitat. Pools and undercut banks provide the main habitat for fish downstream of the culvert, and they area most beneficial to juvenile salmonids and migrating adults. Spawning gravels are present in one location, but most of the area downstream of the culvert does not support spawning behavior.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of Big Scandia Creek.

2.7.1 Reference Reach Selection

The reference reach is an 80-foot reach of stream that begins approximately 180 feet downstream of the culvert outlet, extending to a distance approximately 260 feet downstream of the culvert outlet (station 0+20 to 1+00) (see Figure 7). This section was chosen because it is downstream from the influence of the culvert and what appears to be a straightened and steepened section of stream where the channel runs adjacent to the toe of the Cox Avenue NW roadway embankment. No signs of chronic erosion and deposition were observed in this reach, and the sediment size distribution did not significantly change between the upstream and downstream sides of the existing culvert. The reference reach has overbanks accessible to flooding with a combination of pools (1.5 feet deep) and shallow sections resulting from in-channel aggradation of sandy and gravelly material. The reference reach contains mature trees without a dense understory (Figure 30).

Figure 30: Reference reach, looking upstream at BFW-6 near STA 0+35

Other reaches were considered but rejected because of possible or confirmed human influences. The 300 feet of channel upstream of the culvert is in a low-relief area with a high degree of sinuosity that was thought to be artificially graded during the site visit. Later hydraulic modeling showed that this section is backwatered during large flow events (see Section 5.2) making this reach unsuitable as a reference reach. Upstream of this 300-foot-long sinuous meander section the channel runs adjacent to Cox Avenue NW and was likely impacted by the roadway construction and is also not suitable to use as a reference reach.

Field observation of the reference reach estimated that the channel slope in this area was roughly 0.6 percent. Measurements from survey and LiDAR data show the channel slope is closer to 0.8 percent. Conditions within the reference reach were characterized by BFW measurements in two places (see Section 2.7.2) which averaged to 12.5 feet. Sediment distribution was measured from one pebble count taken within the reference reach as discussed in Section 2.7.3.

Concurrence on the location of the reference reach by WDFW and the Quinault Tribe was obtained during Site Visit 3 on December 17, 2021.

2.7.2 Channel Geometry

The Big Scandia Creek channel has moderate sinuosity, a low gradient (0.8 percent) plane-bed planform geometry with pools, and high flows overtop the main channel to access the floodplains. The channel is unconfined, as the floodplain utilization ratio is greater than 3.0 (see Section 2.7.2.1). The high flow events have significant depth through the floodplain (greater than 2 feet during the 100-year event), and these areas carry active flow across them. The visible floodplain is about 80 feet wide. See Section 2.7.2.1 for details about the flood-prone widths. The channel evolution stage is estimated to be in Stage IV, degradation and widening, according to the stream evolution model depicted in *Providing Aquatic Organism Passage in Vertically Unstable Streams* (Castro and Beavers 2016).

The cross-sectional geometry of the channel is well defined with stable banks. Two BFW measurements were obtained within the reference reach (See Figure 31 and Figure 32) resulting in an average BFW of 12.5 feet. Bankfull was identified by an inflection point in the channel bank slope. The water depth ranged from 0.5 to 1.5 feet in the reference reach, which has a slope of 0.6 percent, at the time of the site visit. As seen in the figures, the water depths were below bankfull depths. In the reference reach the bank heights ranged from 1.0 to 2.5 feet, and bank slopes were steep ranging from 1:2 to 1:3 (Horizontal:Vertical). This results in width to depth ratios that range from 5 to 12.5. The banks are composed of fine and sandy material supported at the reported slopes primarily by tree roots.

The channel geometry is similar upstream of the reference reach as well as upstream of the culvert crossing. Four BFW measurements were taken upstream of the culvert ranging from 10 to 14 feet (see Figure 33, Figure 34, Figure 35, and Figure 36). The channel is shallower at these locations with depths ranging from 0.5 to 1.0 feet. Because the upstream reach is influenced by culvert backwater to station 8+00, the upstream measurements were not included in the average BFW for the overall channel. The average BFW will be used to guide the selection of the main channel width as described in Section 4.1.1.

Figure 31: BFW-5 measurement of 10 feet, measured within the reference reach near STA 0+95

Figure 32: BFW-6 measurement of 15 feet, measured within the reference reach near STA 0+35

Figure 33: BFW-1 measurement of 14 feet, measured near STA 5+00

Figure 34: BFW-2 measurement of 10 feet, measured near STA 5+20

Figure 35: BFW-3 measurement of 12 feet, measured near STA 5+60

Figure 36: BFW-4 measurement of 12 feet, measured near STA 6+20

Bankfull widths are summarized in Table 3. BFW measurements range between 10 and 15 feet in the reference reach. These locations are outside the limits of the topographic survey, so an approximate cross section was created in CAD based on field observations for use in the hydraulic model. A sample cross section from the surveyed channel was included with these approximations in Figure 37 for comparison. The measured BFWs and hydraulic opening were discussed with WDFW staff and Quinault Tribal representatives during a site visit on December 17, 2021. An average bankfull width of 12.5 feet was agreed upon. This agreed upon BFW will be used to inform the width of the main channel while the unconfined bridge method, governed by the velocity ratio, will guide the minimum structure opening size (see Section 4.2).

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured	Concurrence notes
1	12	No	Upstream at straight stream section (STA 5+00)	
2	12	No	Upstream at meander bend (STA 5+20)	
3	10	No	Upstream at straight stream section (STA 5+60)	
4	14	No	Upstream at meander bend (STA 6+20)	
5	10	Yes	Upstream end of reference reach (STA 0+95)	Stakeholder concurred on 12/17/2021
6	15	Yes	Near downstream end of reference reach (STA 0+35)	Stakeholder concurred on 12/17/2021
Design Average	**12.5**			Stakeholder concurred on 12/17/2021

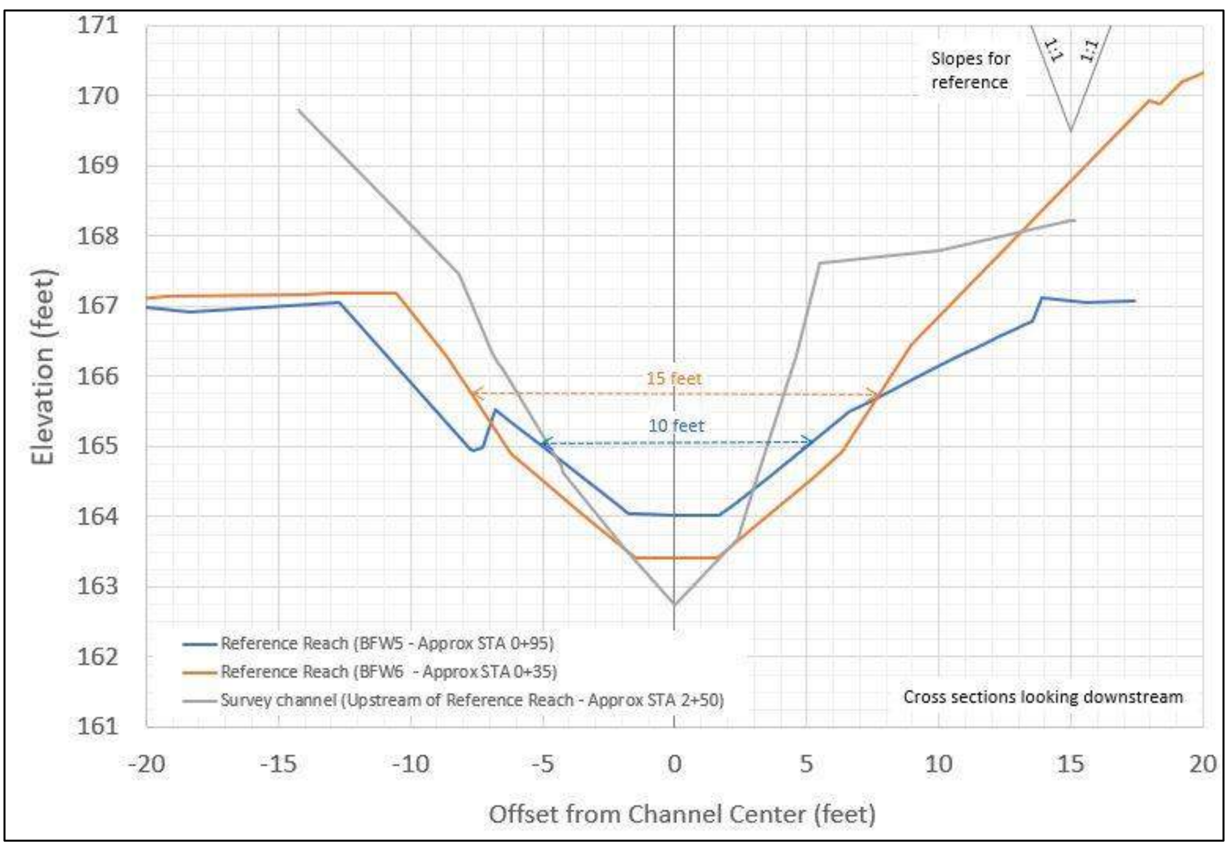


Figure 37: Existing cross-section examples

2.7.2.1 *Floodplain Utilization Ratio*

Floodplain utilization ratio (FUR) is an indication of how entrenched the channel is. It is a ratio of the flood prone width divided by the BFW. The flood-prone width (FPW), which is the water surface width at twice the bankfull depth, is estimated by the width that is inundated during a peak flow 100-year event. Figure 38 shows the extent of the 100-year floodplain and the locations where the FUR was measured.

The project team determined the flood prone width of Big Scandia Creek based on the topographical survey data and the natural conditions SRH-2D model during the 100-year flow event and the agreed upon BFW. FPW measurements were taken in the natural conditions model to avoid the backwater conditions created by the undersized culvert. The natural conditions grading replaced the existing 6-foot diameter culvert with a 12.5-foot-wide channel with a 25-foot meander width and a 0.6 percent channel gradient with gradually sloped banks extending outside the floodplain. This channel was modeled based on the BFW established with WSDOT and the co-managers, the typical meander width in the reference reach, and the average slope between the upstream and downstream channels (see Section 5.3 for more information). The FUR is greater than 3.0 at all cross sections where it was measured. The average FUR for the channel is 7.1 (see Table 4), so the channel is considered unconfined as specified by the WCDG (Barnard et. Al., 2013).

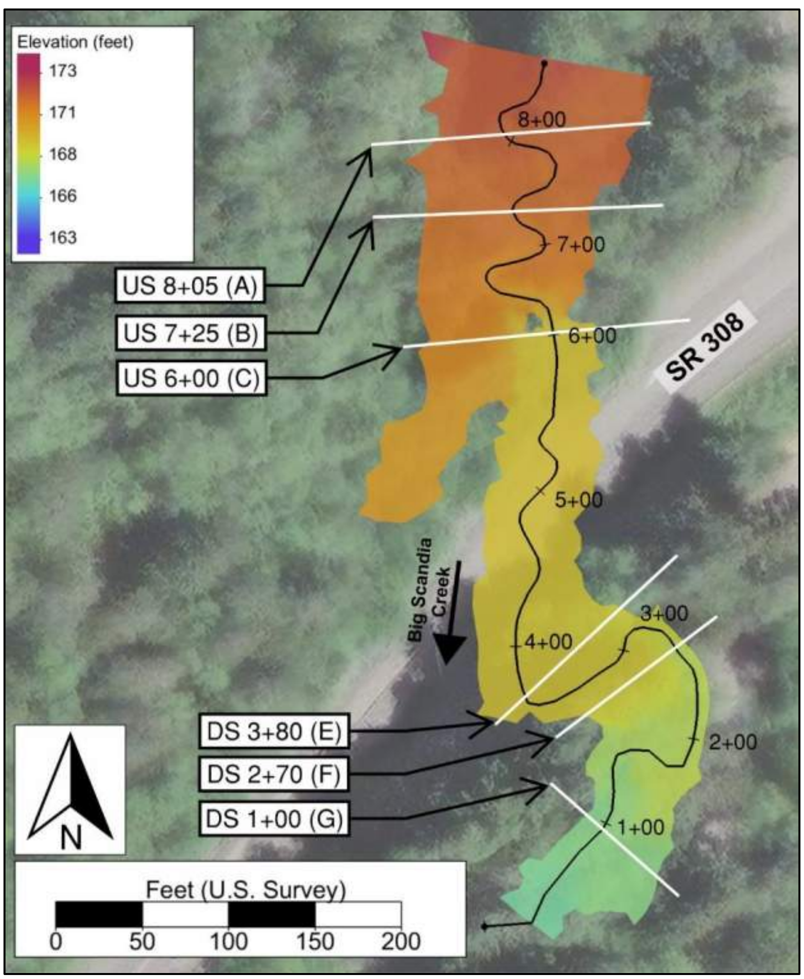


Figure 38: FUR locations with 100-year flow depths

Table 4: FUR determination

Station	FPW (ft)	FUR	Confined/unconfined	Included in average FUR determination
DS 1+00 (Reference Reach)	54.9	4.4	Unconfined	Yes
DS 2+70	71.3	5.7	Unconfined	Yes
DS 3+80	94.7	7.6	Unconfined	Yes
US 6+00	96.9	7.8	Unconfined	Yes
US 7+25	95.9	7.7	Unconfined	Yes
US 8+05	119.3	9.5	Unconfined	Yes
Average	**88.8**	**7.1**	**Unconfined**	**Yes**

2.7.3 Sediment

One Wolman Pebble Count (PC) was conducted at this site within the reference reach. The results of the PC are contained in Table 5. Additional PCs were not taken as the streambed sediment was homogenous and very fine. Pebble counts were not conducted upstream of the culvert because, within the sinuous reach it was observed that the bed material consisted entirely of sands less than 2 mm (Figure 39). The bed material in the reference reach is also relatively small but contains some degree of gravel as shown in Figure 40 and Figure 41.

In the deeper portions of the stream the channel bed sediment was dominated by clean sand. In shallower portions of the stream some pebbles and gravels were observed on top of the sand. This indicates that the low gradient portion of the channel is low energy and deposits sand within the channel until it can be transported through as bed load or suspended load during high flows. As shown in Figure 25 near station 2+00, pebbles and gravel provide an armoring layer in this low energy stream. It is possible for sandy streambed material to be located below the gravel bar near station 2+00. There were no sand deposits observed on the overbanks indicating that flood flows in the overbank are not energetic enough to transport the sand from the channel to the overbank.

Coarser alluvial material was observed in two places. First where a drainage ditch enters the channel approximately 25 feet downstream of the culvert on the left side of the stream, and second where the channel was likely realigned and steepened adjacent to Cox Avenue NW. This indicates that coarse alluvium likely underlays the channel and overbank area but was only observed at the surface at locations where the channel had been likely modified.

Figure 39: Sandy bed material within the sinuous portion of the channel upstream of the culvert

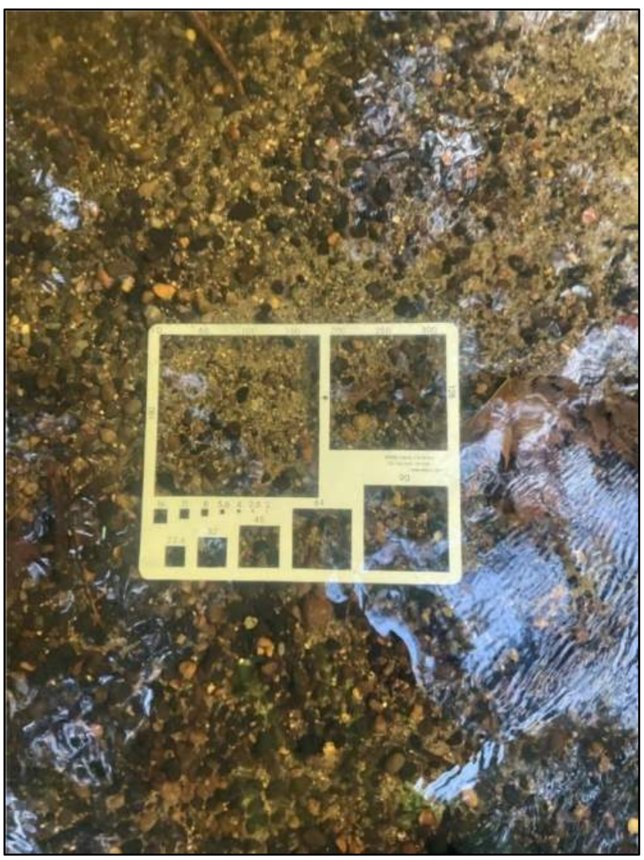


Figure 40: Gravelly streambed material in the reference reach where the pebble count was measured (Approx STA 0+50)

Figure 41: Typical sediment in pebble count location (Approx STA 0+50)

Table 5: Sediment properties near the project crossing

	Site PC 1 Downstream Diameter (in)	Average Diameter (in)
D_{16}	0.03	0.03
D_{50}	0.13	0.13
D_{84}	0.57	0.57
D_{95}	1.05	1.05
D_{100}	1.26	1.26

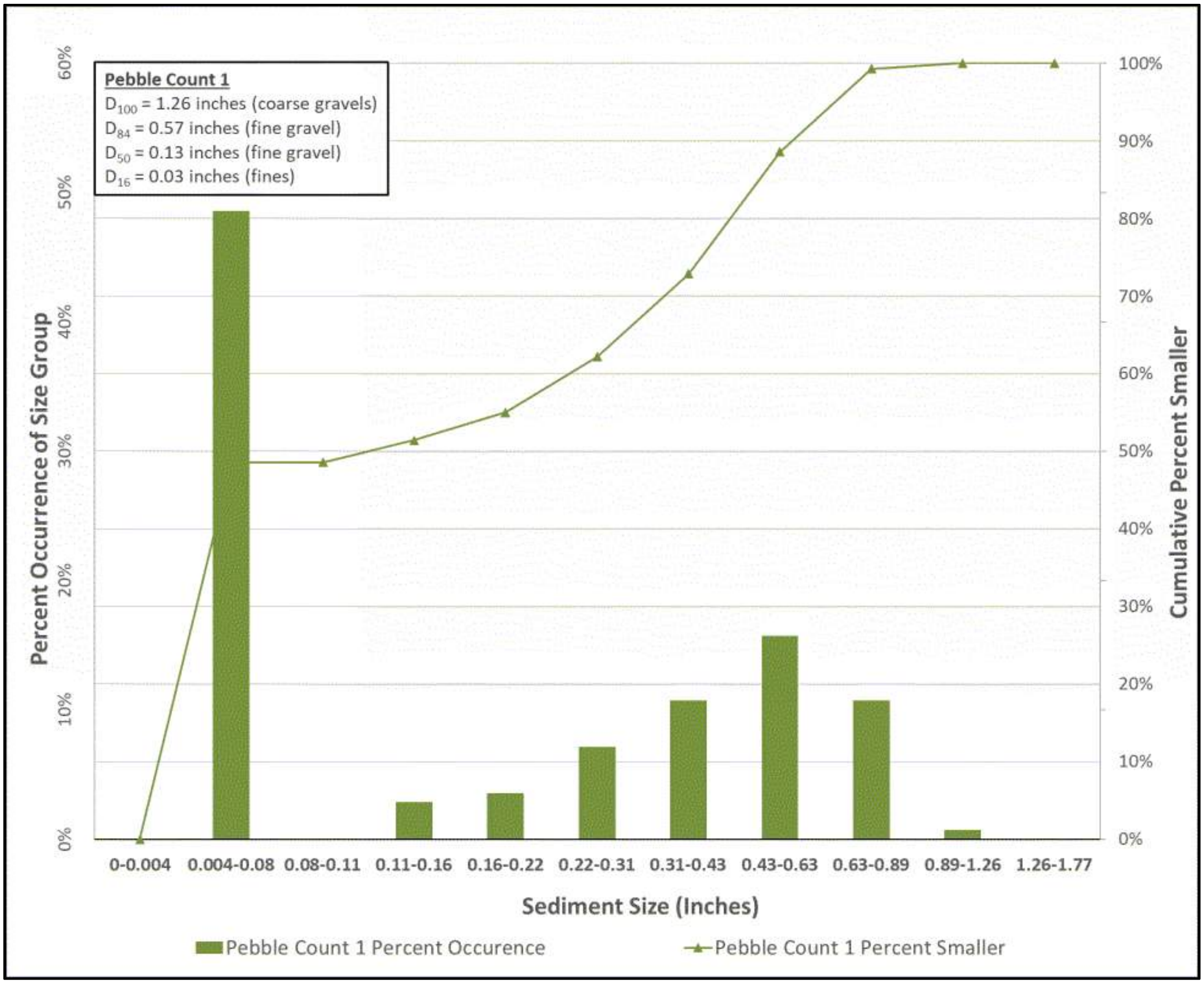


Figure 42: Sediment size distribution

2.7.4 Vertical Channel Stability

The existing culvert is in line with the channel gradient and there is no chronic aggradation or degradation resulting from flow through the culvert. The upstream end of the culvert is not blocked (Figure 43). The downstream end of the culvert has a shallow scour pool that is supported by a constructed grade control structure consisting of large rock and wood material (Figure 44). This pool is assumed to provide low flow backwater to improve fish passage. The vertical water surface drop across this grade control was visually estimated to be 3 inches. Other than this grade control, the culvert does not influence the longitudinal slope or vertical channel stability.

Figure 43: Upstream end of culvert

Figure 44: Downstream end culvert with shallow scour pool with grade control consisting of large rock and wood material

The dominance of sand in the channel indicates a depositional or transport reach with flows that are insufficient to mobilize coarser material. The sand was observed to be loosely packed with ripple patters in some locations that indicates that the sand is readily mobilized through the system as either suspended load or bed load. There are steep banks upstream of the culvert (Figure 45), but they appear to be stable with no active or recent erosion. This indicates that transported material is entering the channel in upstream reaches.

The long profile shown in Figure 46 was developed using LiDAR data. Because LiDAR data does not include the channel bathymetry, the data appears 1 to 2 feet above the channel bottom that is indicated by the surveyed data. However, the data is still useful in evaluating the general slope of the long profile. Both the LiDAR and surveyed data show the same slope through vicinity of the crossing. The data does not indicate the presence of a grade break between the upstream and downstream sides of the culvert, but there is a generally convex curve through the long profile. The downstream crossing at Cox Avenue NW and the upstream private road crossing act as stable grade control points for the channel through SR 308. If SR 308 at this crossing was removed, the channel would likely degrade about 2 feet from its current elevation as indicated in Figure 46. See Section 7.2, for additional discussion about long term degradation.

Figure 45: 180-degree meander bend upstream of the culvert with sand bed material showing ripple patterns

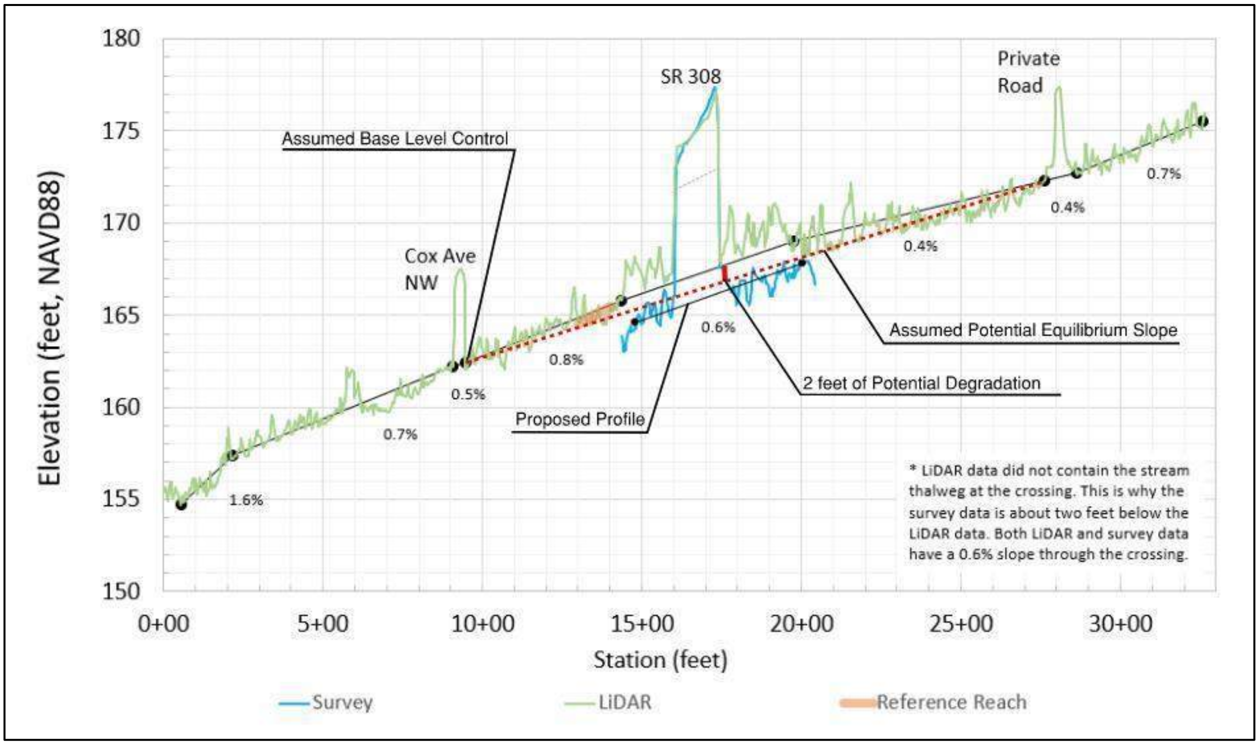


Figure 46: Watershed-scale longitudinal profile

2.7.5 Channel Migration

No evidence of recent channel migration was observed during the site visits or noted in LiDAR topography. Wide scale lateral migration of Big Scandia Creek is limited by Cox Avenue NW, SR 308, and the adjacent topography. Many of the meander bends are constrained by trees and roots that create stable banks, but a risk for local lateral migration within the identified meander belt width (see Section 4.1.1) is possible. The sinuosity of the meander bends ranges from zero upstream of station 8+00 to very high in the reach upstream of the culvert. The downstream reach is moderately sinuous. The banks are generally vertical even along the inside of meander bends due to the clay content of the bank material and the density of tree roots. Trees with undercut roots leaning towards the channel were commonly observed (Figure 47) indicating that channel adjustments due to erosion of the banks may occur when trees fall, which may be a slow and long-term process. Vertical channel erosion is also possible as discussed in Section 2.7.4.

The floodplain of Big Scandia Creek is about 80 feet wide and contains flows greater than 2 feet during the 100-year event. Flow paths through the floodplain were not discernable during the field visits, but the hydraulic modeling results in Appendix H show a faint flow path on the right side of the stream from approximately station 7+50 to station 5+50 that encompasses almost the entire floodplain width. Big Scandia Creek may shift laterally within the floodplain but shifts greater than the meander belt width of 25 feet discussed in Section 4.1.1 are not expected. Due to the watershed long profile having a generally convex shape (see Figure 46) and the presumed permanence of the upstream and downstream crossings, long term degradation is anticipated which will decrease the chance of channel migration as the main channel becomes more incised as long-term degradation occurs.

Figure 48: **Mature tree tilting into stream and slight bank undercutting at start of reference reach**

3 Hydrology and Peak Flow Estimates

The basin receives an annual average precipitation of 41.8 inches (PRISM Climate Group 2021). There are no streamflow gages located on Big Scandia Creek, and no stream gages on similarly sized streams nearby. Simulated flows were evaluated from two sources: the USGS web app StreamStats that utilizes regression equations (USGS 2016) and the MGSFlood software package that utilizes continuous hydrologic modeling. Results from these sources are compared in Table 6. This comparison shows that MGSFlood flows are larger except for the 2-year flow return period. The 2-year flow is critical for verifying bankfull flow depth in a stream. The USGS and MGSFlood 2-year flows were tested in the hydraulic model developed for this site (see Section 5) to compare modeled 2-year event water surface widths to measured BFWs in the field. Results from hydraulic modeling indicated that the 2-year flows from the USGS regression equation provided a slightly better representation of a bank full flow for the measured channel geometry. However, to avoid mixing hydrologic methods, the more conservative MGSFlood values were used for all recurrence intervals as they are the most appropriate for the reasons stated above. Precise accuracy of the peak flows is not quantifiable as the parameters used to develop them are based on broad data sets with various levels of accuracy such as soil type, land cover usage, LiDAR topography, and agreed upon bankfull width measurements in the field. Indicators of appropriate flows such as scour lines, high flow debris, or conversations with adjacent landowners were not available to help determine appropriate flows for Big Scandia Creek at this crossing.

This crossing is within the same system as two other crossings, which also require PHDs. DEA is completing the PHDs for the upstream crossing (SR 3 MP 49.48) and the downstream crossing (SR 308 MP 1.15). The hydrological analysis for all three sites was performed together to maintain consistency within the system. Due to the differences in the watershed slopes, land use, and shape of the drainage basins for these three sites, it is believed that the USGS regression equations, which only evaluate watershed area and mean annual precipitation to estimate peak flows, do not produce consistent hydrological results across the three sites. MGSFlood provided the most consistent hydrological results for all three sites compared to USGS regression equations. The channel is not expected to run dry in the summer, however low flow conditions are not quantifiable.

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for a nearby project site, as the WDFW Culverts and Climate Change online application could not delineate a drainage basin for Big Scandia Creek at SR 308 MP 0.94. The design flow for the crossing is 180 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 64 percent, yielding a projected 2080 100-year flow of 296 cfs.

Table 6: Peak flows for Big Scandia Creek at SR 308

Mean recurrence interval (MRI) (years)	USGS regression equation (Region 3) (cfs)	MGSFlood (cfs)
2	34	**28**
10	68	**71**
25	86	**104**
50	100	**131**
100	115	**180**
500	150	**185**
Projected 2080 100	240	**296**

4 Water Crossing Design

This section describes the water crossing design developed for SR 308 MP 0.94 Big Scandia Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for Big Scandia Creek at SR 308 MP 0.94. The proposed design uses one typical cross section shape that is implemented over 240 feet of channel grading with a grade of 0.6 percent.

The main objective of the channel design is to remove the fish passage barrier, identified as excessive slope, that exists in the culvert. The design process supports the replacement of the existing structure by an appropriate hydraulic structure that can simulate the natural processes that support fish passage as observed in the reference reach. This design process also attempts to simulate natural flow transitions from adjacent reaches to and from the proposed structure. Design for simulation of natural processes to support fish passage includes designs that emulate the channel shape, planform, alignment, and gradient of the natural channel.

The design of the channel shape simulates the average measured BFWs within the reference reach and includes distinct slopes for the banks and channel bottom. The proposed channel cross section is not intended to vary in shape along the length of the proposed alignment. The design also includes uniform grading of the channel section to seamlessly transition to the existing channel and thereby maintaining adequate depth and flow velocity for fish passage. The stream assessment determined the targeted channel slope to be 0.6 percent by comparing the slopes of adjacent reaches. The design relocates the existing channel alignment to eliminate a sharp bend immediately downstream of the culvert outlet and provide a smooth transition from the structure to the channel (see section 4.1.2). The proposed alignment allows a section of existing channel near the outlet to be converted to off-channel habitat.

4.1.1 Channel Planform and Shape

The WCDG (Barnard et al. 2013) recommends that a proposed stream channel have a gradient, cross-section, and general configuration that are similar to the existing channel upstream and downstream of the proposed crossing, provided that the adjacent channel has not been modified in a way that adversely affects natural stream processes. The site visit evaluated existing conditions for Big Scandia Creek both upstream and downstream of the SR 308 crossing (see Section 2) to provide the baseline characteristics for the design. The proposed channel shape is designed to mimic the existing sections observed in the reference reach and measured from the field data and surveyed channel section. The channel shape largely dictates hydraulic properties such as flow depth, velocities, and bed shear stress.

In the reference reach, the bank heights ranged from 1.0 foot to 3.0 feet, and bank slopes were steep, ranging from 2:1 to 3:1 (H:V) (See Figure 48). The reference reach cross-sections shown in Figure 48 were created using LiDAR data because the available survey data does not extend to the downstream reference reach. The channel shape was verified by observations during site visits which provides confidence in the channel cross section shape.

Observed channel banks at the project site were relatively stable and did not show signs of aggradation or degradation in the reference reach, so these channel geometries were used to determine the proposed channel cross section including bank slopes. Using the existing bank morphology to determine the proposed design will support flow regimes through the constructed reach consistent with channel processes seen in the reference reach. These processes include sediment transport that is expected to remain steady after construction with no incision of the channel bed or aggradation of sediments on the bed.

Designing the proposed channel section based on bank heights and widths from the reference reach means that flow depths and velocities for fish passage as well as habitat will be close to natural conditions during low or high flows. A channel that is too wide can result in lower flow depth during low-flow periods, and narrow sections can result in higher velocities than natural conditions that could cause bed scour and in turn adversely affect fish passage and habitat. This low gradient channel, which has a plane-bed morphology with pools at meanders, is intended to provide adequate depth and flow velocities, so salmonids can use it across all life stages.

The proposed channel width is 12 feet which is referred to as the design bankfull width and has a bankfull depth of 2.2 feet. The 4-foot-wide V-shaped low flow channel is bounded by 2:1 (H:V) side slopes. To incorporate this typical cross-section within the structure, floodplain benches were added at 10:1 (H:V) slope. The proposed typical section (see Figure 49) is shown in comparison to the reference reach cross section in Figure 48. BFW and bank heights of the proposed channel are similar to the existing channel geometry. Figure 49 shows the 2-year flow depth through the crossing. The 2-year flow results in a flood width of 11.3 feet, which is less than the design bankfull width of 12 feet. However, the existing and natural conditions 2-year hydraulic modeling results also do not fill the channel width, as discussed in Section 5.2. Although the proposed channel does not meet the design BFW, the difference is likely a hydrological discrepancy rather than an issue with the channel geometry.

In later stages of the project, a low-flow channel will be added that connects habitat features together, so the project will not become a low-flow barrier. The low-flow channel will be constructed as directed by the engineer in the field.

Following construction, the channel shape is expected to change as channel processes adjust to the new crossing. Over time the proposed channel section will stabilize and create a natural transition between the structure and the adjacent natural channel. However, this change is dependent not only on the proposed channel shape, but also on the channel gradient, changes in the upstream hydrology, and other site constraints.

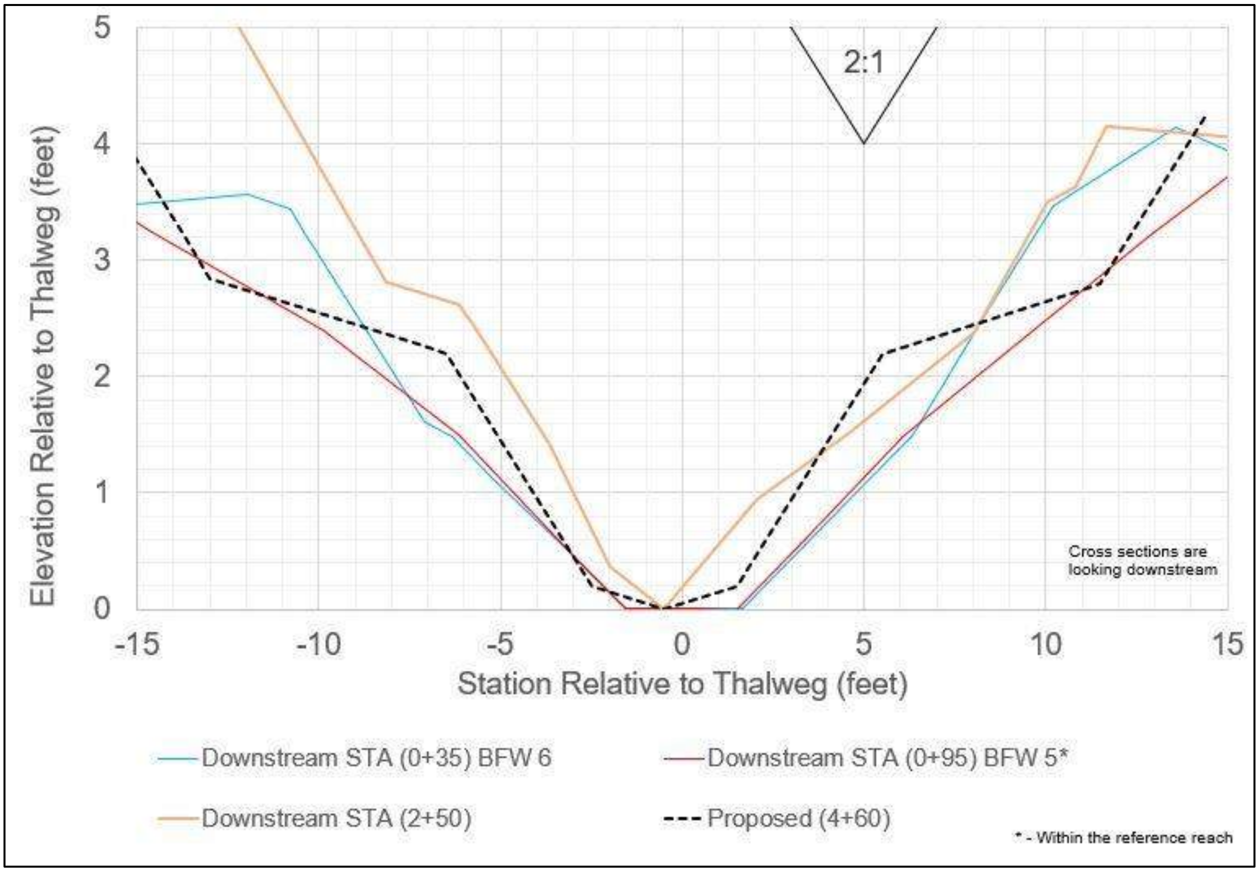


Figure 48: Proposed cross section superimposed with existing survey cross-sections

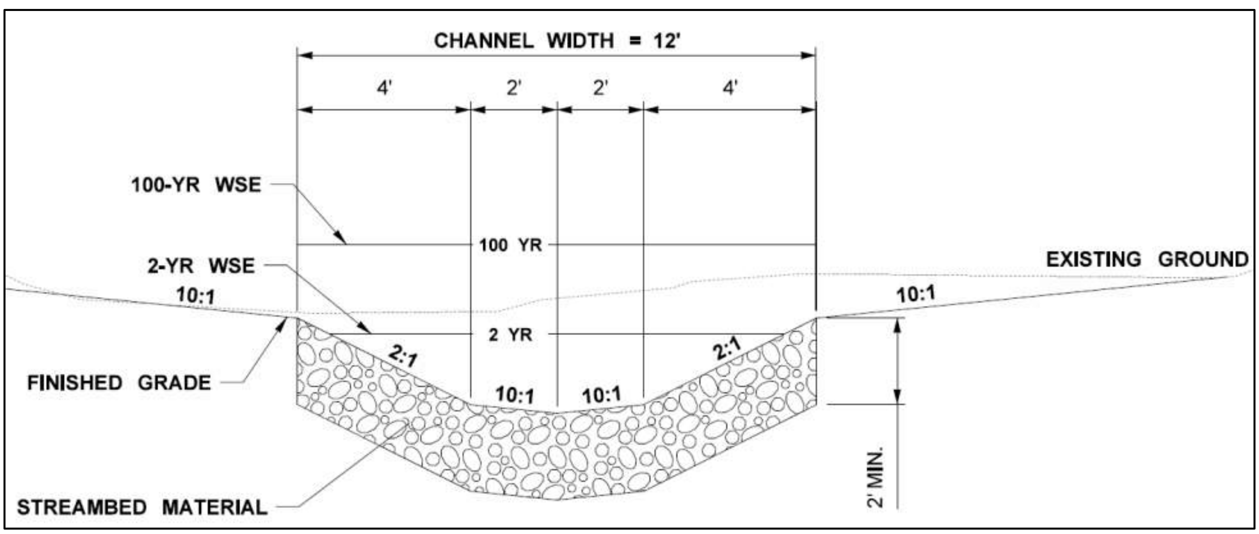


Figure 49: Design cross section

A meander belt width assessment was conducted due to the unconfined nature of the channel and the natural meander of the existing channel downstream of the crossing. The analysis of meander belt width was performed using LiDAR data of the reaches upstream and downstream of the crossing (Figure 50). Meander belt width is usually estimated using the channel alignment immediately upstream and downstream of the culvert. However, the hydraulic model results showed the upstream reach is heavily influenced by backwater conditions. The downstream section is influenced by the culvert as well as Cox Ave NW on the east. A section upstream of the surveyed section (shown as black dashed box in Figure 50) was assumed to have the least influence from roads and structures and was used to estimate the meander width. The meander belt width was estimated to be a minimum of 25 feet. This meander width was used to recommend the minimum hydraulic width for proposed conditions (see section 4.2.2). Figure 50 also shows how LiDAR was used to estimate a stream alignment in natural conditions.

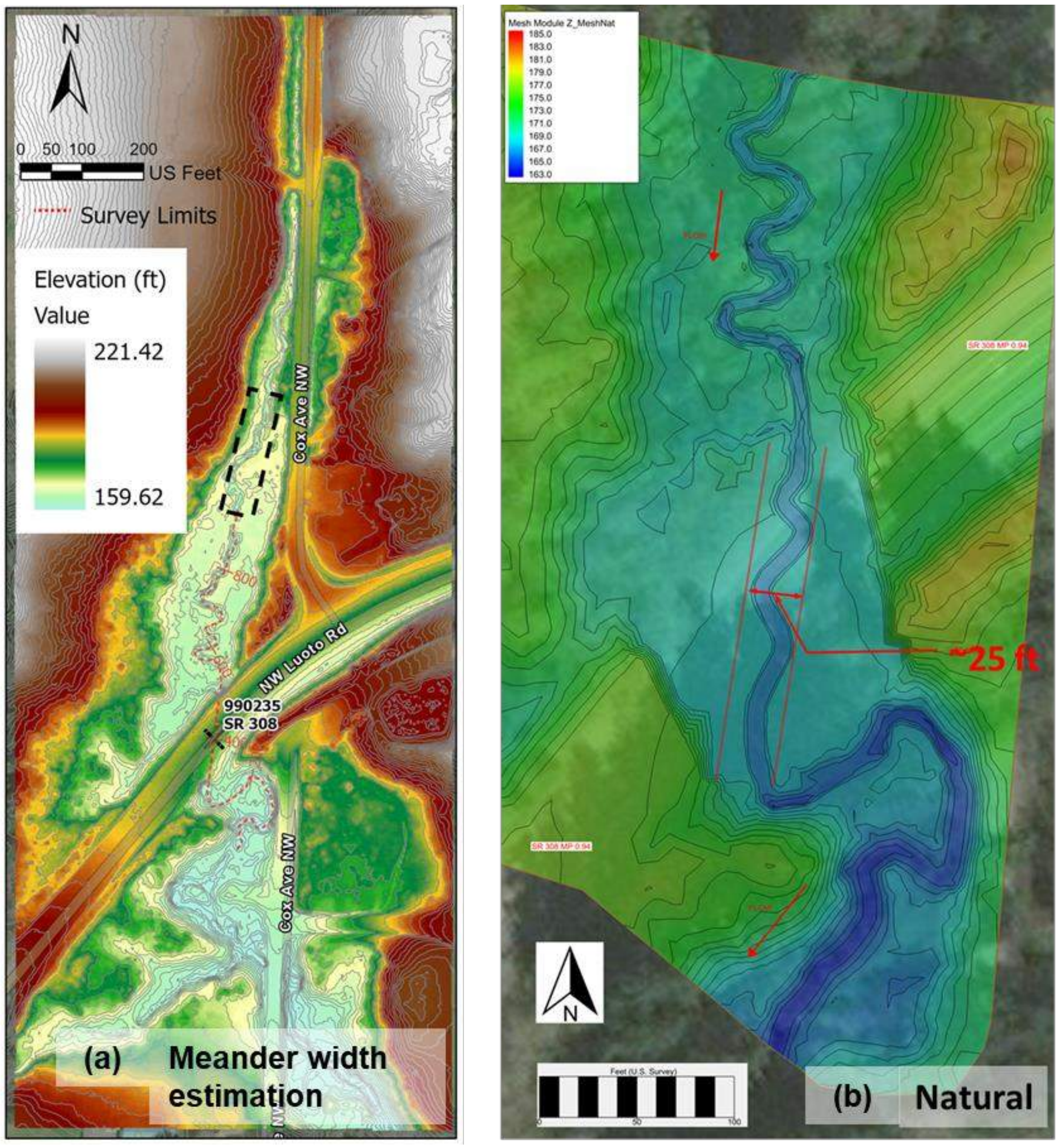


Figure 50: Estimation of meander width and its application to design and modeling of natural conditions

4.1.2 Channel Alignment

The existing culvert crosses SR 308 at a skew angle of 31 degrees (Figure 51). Based on the likely historical channel alignment, it is believed the channel was realigned to avoid conflicts with Cox Avenue NW while staying close to the original alignment. This produced sharp bends in the stream curvature as it follows these artificial features. The radius of curvature of these bends is roughly 13 feet. WCDG recommends the radius of curvature of a design stream be at least five times the bankfull width. With the BFW of the stream established as 12.5 feet, this would require the minimum radius of curvature be at least 63 feet. Meetings with WDFW, WSDOT, and Quinault tribe representatives resulted in the agreement that the stream alignment should be adjusted to a roughly 50-degree crossing to better align with the channel along Cox Avenue NW and eliminate the stream bends immediately downstream of the culvert (Figure 51). This will shorten the crossing length from 140 feet to approximately 127 feet. The existing scour pool and downstream channel will remain as preserved backwater habitat. The length of the proposed channel grading is 240 feet. The alignment through the SR 308 crossing is straight, however a sinuous low flow channel will be added during construction as detailed in the plan sheets contained in Appendix D.

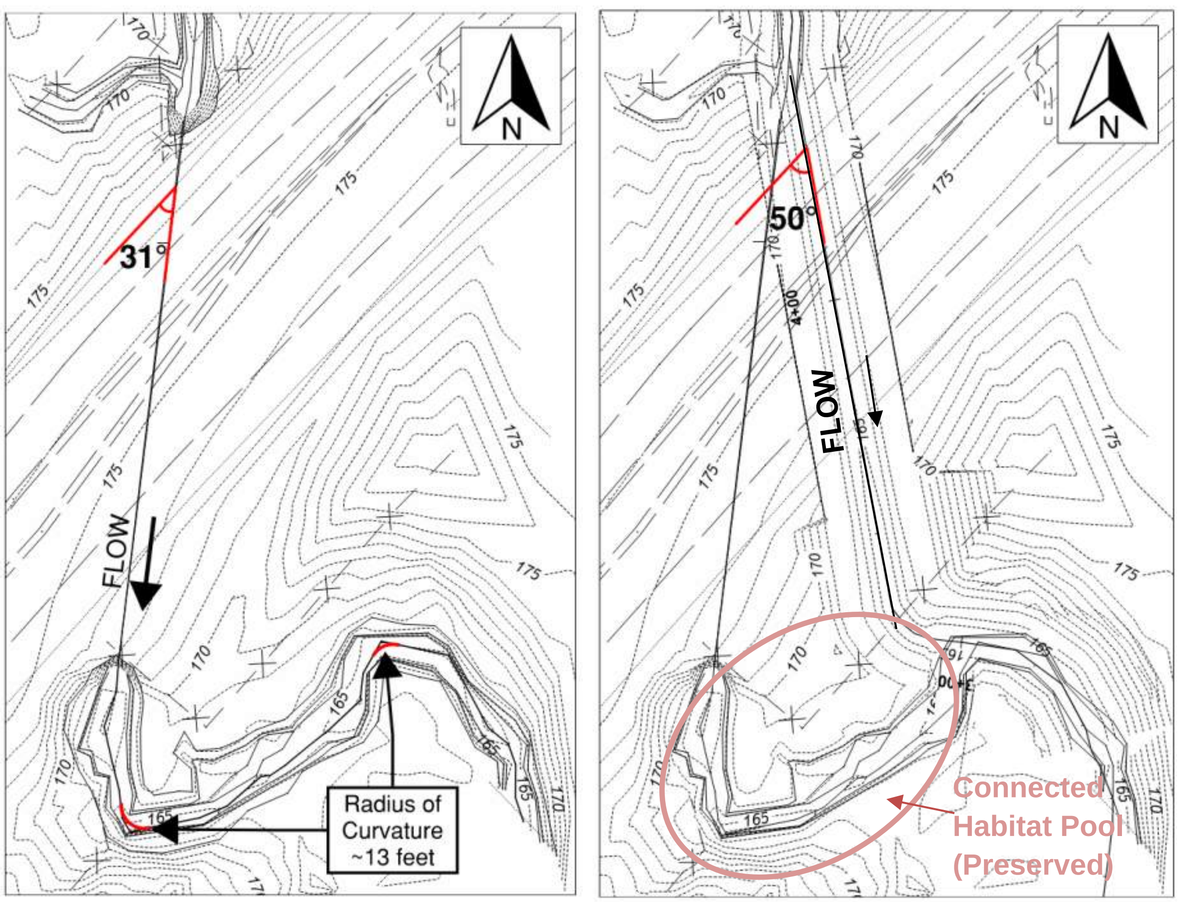


Figure 51: Existing alignment (left) and proposed alignment (right)

4.1.3 Channel Gradient

The proposed upstream channel tie-in point is at station 4+94, which is roughly 21 feet upstream of the proposed SR 308 crossing. The proposed downstream tie-in point is at station 2+54 which is roughly 92 feet downstream of the proposed crossing. These tie-in locations were selected to avoid scour pools and create a uniform and stable profile in the existing thalweg. The tie-in locations also mimic as closely as possible the adjacent existing stream grades.

The WCDG recommends the proposed stream channel gradient be no more that 25 percent steeper than the upstream channel gradient, thus providing a limiting slope ratio of 1.25 (WCDG Equation 3.1). The slope of the proposed channel between tie in points is 0.6 percent, while the existing upstream is 0.6 percent which results in a slope ratio of 1.07. The slope of the reference reach is also about 0.6 percent. The slight difference in the channel gradients will produce minimal long-term aggradation and degradation. See section 7.2 for further discussion on long-term degradation.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour depths. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour depths see Section 7. See Figure 52 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

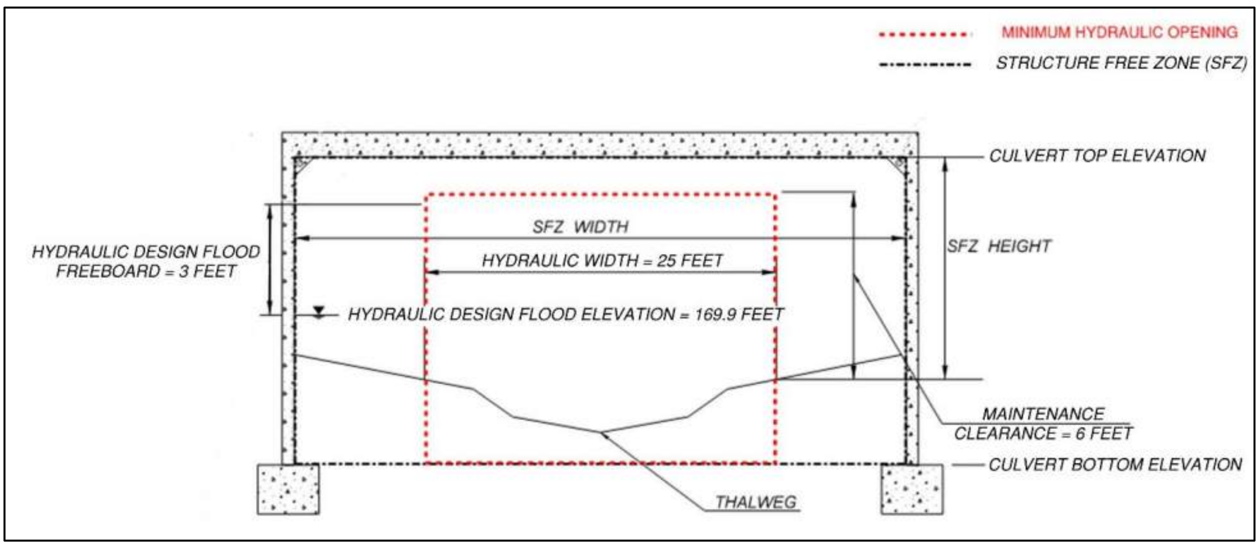


Figure 52: Minimum hydraulic opening illustration – for illustration purposes only (NOT TO SCALE)

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022). Using the guidance in these two documents, the unconfined bridge design method was determined to be the most appropriate at this crossing due to limiting factors based on the FUR, BFW, slope ratio, and allowable height of the road.

The average FUR for this site is 7.1 (see Section 2.7.2.1), which makes the unconfined bridge method the most appropriate for determining the minimum hydraulic opening per the WCDG. The agreed upon BFW is 12.5 feet, measured within the reference reach (see Section 2.7.2), the slope ratio of the proposed channel is 1.07 (see section 4.1.3), and the existing channel is vertically and horizontally stable.

The proposed crossing length is roughly 127 feet (see section 4.1.2). Project fill will be limited to the roadway. The roadway is roughly 8 feet above the proposed channel bottom, so minimal fill is anticipated. An unconfined bridge approach will be used to replace the existing culvert in a manner that will provide the most habitat, permit natural processes to take place through the channel, and increase the climate resilience of this site by drastically increasing the hydraulic opening.

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 17 feet was determined to be the minimum starting point. This 17-foot width is the larger of the result from the WCDG Equation 3.2 (1.2 x BFW + 2 feet) and the WSDOT Equation of 1.3 x BFW, which results in a width of 16.3 feet.

The WCDG also recommends that the minimum hydraulic width be increased under specific conditions that include if the structure length is more than 10 times the span (a “long culvert”), there is excessive backwater, the velocity is higher through the crossing than in the adjacent undisturbed reaches, channel migration is anticipated, or if there is natural sinuosity of the channel. Evaluation of these criteria found that this crossing is not considered a long culvert, and it is expected that channel migration will be limited. However, the channel does exhibit natural sinuosity. Evaluation of the meander belt width (the width of the sinuosity) indicated that increasing the minimum hydraulic opening to 25 feet is warranted. Section 4.1.1 details the estimation of the meander belt width for Big Scandia Creek at this crossing. Hydraulic testing of the 25-foot hydraulic width demonstrated that this opening width will not cause backwater and will not significantly increase velocities through the crossing (see Section 5.4). The 25-foot hydraulic width analysis was conducted for a 127-foot length, so any hydraulic length greater than 127 feet should be reevaluated. The WSDOT *Hydraulics Manual* requires that the velocity ratio (ratio of the velocity through a structure to the velocity immediately upstream of the structure) during the 100-year event be equal to or less than 1.1. The velocity ratio according to the velocities in Table 7 is 1.09, which conforms to the velocity ratio requirements.

Based on the factors described above, a minimum hydraulic width of 25 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The projected 2080 100-year flow event was also evaluated. Table 7 compares the main channel velocities of the 100-year and projected 2080 100-year events. The maximum velocities during the 100-year and projected 2080 100-year events in the floodplains are 2 feet per second and 4 feet per second respectively.

Table 7: Velocity comparison for 25-foot structure

Location*	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Reference reach (STA 1+00)	3.9	4.1
Upstream of structure (STA 4+88)	3.6	3.7
Through structure (STA 3+79)	3.9	4.8
Downstream of structure (STA 3+13)	3.5	4.4

*Stations are based on proposed alignment shown in Figure 7.

No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results see Section 5.4.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8.

The minimum required freeboard at the project location, based on BFW, is 3 feet above the 100-year water surface elevation (WSE) (Barnard et all. 2013, WSDOT 2022a). However, the WSDOT *Hydraulics Manual* requires 3 feet of freeboard for all structures greater than 20 feet and on all bridge structures unless otherwise approved by HQ Hydraulics (WSDOT 2022a). The proposed crossing is a 25-foot-wide bridge structure and as such will be held to this minimum freeboard of 3 feet above the 100-year WSE.

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.7 feet for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or large woody material. If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 do not include elements of significant size and will not need to be maintained with machinery. If it is practicable to do so, a minimum maintenance clearance of 6 feet is recommended for maintenance and monitoring purposes but is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width.

The existing conditions indicate that the fill above the culvert is about one to three feet in height. With the current proposed hydraulic design, it is expected that the minimum freeboard could be attained with changes in the design of roadway. However, it is unlikely that recommended freeboard can be attained without significant changes in roadway design, which could include raising the roadway. Detailed design and analysis will be done in the later phases of the project.

Table 8: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	3+47	4+74
Thalweg elevation (ft)	164.8	165.5
Highest streambed ground elevation within hydraulic width (ft)	167.7	168.4
100-year WSE (ft)	168.7	169.2
2080 100-year WSE (ft)	169.3	170.0
Required freeboard (ft)	3	3
Recommended maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	171.7	172.2
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	172.3	173.0
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	173.7	174.4
Required minimum low chord (ft)	**172.3**	**173.0**
Recommended minimum low chord (ft)	**173.7**	**174.4**

4.2.3.1 Past Maintenance Records

WSDOT Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage or removal of sediment at this crossing.

4.2.3.2 Wood and Sediment Supply

The drainage basin for Big Scandia Creek upstream of the crossing is approximately 58 percent forested. There are no known plans for development or land cover changes in the basin including logging or restoration activities. The area from the culvert to approximately 2,000 feet upstream of the crossing is predominantly pasture and woody wetlands which may limit the supply more than dense forested banks would (see Figure 3). During site visits, a single piece of LWM (18-24 inch) was observed in the stream (see Figure 27). However, this is downstream of the culvert, and it is unlikely the stream could transport it any great distance. There is other woody material present in the stream as noted in Section 2.6.2. Given the 100-year flow of 180 cfs, the stream could move moderate sized LWM. We expect that this stream can transport up to an 8-inch diameter log about 10-feet long given that the BFW is 12.5 feet (WSDOT Hydraulics Manual section 10.8). Any log with a larger diameter will likely get stuck at the banks or on trees near the channel. WSDOT does not have records of maintenance at this culvert so, it is assumed that regular maintenance has not been necessary at this crossing.

Figure 4 shows Quaternary Mass Wasting deposits upstream of the crossing, which are typically the result of landslides containing loose and unsorted cobbles, pebbles, sand, silt, clay, and boulders. The meandering stream and undercut banks noted in the field are evidence that stream has sediment supply, and future erosion at the toe of slopes may cause additional landslides and sediment supply to the system. The potential for long term degradation discussed in Section 2.7.4 is partially dependent on the amount of sediment transported from these upstream regions. Long term degradation would increase the vertical hydraulic opening increasing the freeboard over time.

4.2.4 Hydraulic Length

A minimum hydraulic width of 25 feet is recommended up to a maximum hydraulic length of 127 feet. If the hydraulic length is increased beyond 127 feet, the hydraulic width and vertical clearance will need to be reevaluated. It is recommended that a shorter hydraulic length be evaluated, if possible, to allow for increased meander downstream of the crossing.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 308 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for Big Scandia Creek at SR 308 MP 0.94.

4.3.1 Bed Material

The development of the proposed streambed mix followed methods recommended in the WCDG for sizing streambed material in culverts and in the WSDOT *Hydraulics Manual* (WSDOT 2022). The proposed streambed mix design is intended to mimic the PCs measured during the site visits (see Section 2.7.3). The streambed material gradation blends WSDOT standard streambed mixes to develop a bed material mix that is well-graded with larger, less mobile particle sizes and smaller particle sizes to reduce porosity to minimize the potential for flow in the stream to go subsurface during low-flow periods. The finer portion of the gradation will be composed of silts, sands, and small gravels to fill the interstitial spaces of the larger portions of the gradation. See Appendix C for streambed material design details.

The proposed streambed material is 100 percent WSDOT Streambed Sediment (WSDOT Standard specifications 9.03.11(1)). This standard material is a little larger than existing streambed sediments (see Table 9 for comparison), but this streambed material will likely create higher quality spawning gravels because fewer fine particles within the streambed increase the likelihood of spawning in this stretch of the stream for all salmonid species present.

The modified Shields critical shear stress approach, as described in the U.S. Forest Service stream simulation guidelines (USDA 2008), was used to determine whether the proposed sediment sizes will be mobile or stable, as intended, during the full range of design flows. This method compares the critical shear stress for incipient motion for the D_{84} size fraction of the proposed streambed mixture to the average applied shear stress within the proposed grading limits for various return period peak flows. The modified Shields approach is appropriate as the existing stream in the vicinity of the crossing and the proposed conditions have uniform bed material, channel gradients less than 5 percent, and streambed material comprised of sand and gravel. These channel stability calculations indicate that the streambed sediment will be stable for all flow events because the stream has a low gradient which generates low shear stresses. For a streambed mixture to be considered stable the D_{84} must be stable. At higher return period flows, the streambed mobility increases slightly with the D_{50} becoming mobile at 100-year event while the D_{84} is on the fringe of becoming entrained during the 100-year event.

Due to the significant sand mode in the existing stream, particles may become mobile at slightly lower lows than predicted by the modified Shields critical shear stress approach. To evaluate the effect of additional sand aiding the mobility of larger particles, the Shields parameter was reduced as a test but not reported on in Appendix C. The reduction in the Shields parameter led to 10 to 20 percent more of the streambed mix mobilizing at the 50-year, 100-year, and 500-year events, while the stability calculations of the 2-year, 10-year, and 25-year were not affected. This means that the high sand mode in the existing stream may fully entrain the streambed mix during the 100-year event while the streambed mix is stable at flows equal to and less than the 50-year flow.

Boulder clusters are recommended in the channel design to improve habitat complexity, avoid a linear plane bed morphology through the crossing, and avoid entrainment along the structure walls. Boulder clusters will have a minimum spacing of 35 feet through the crossing to increase channel stability as shown in Figure 53 and Figure 54. The 35-foot-spacing is appropriate based on estimations of meander width downstream of the culvert. Boulder clusters will be incorporated such that a low-flow channel can be introduced with enough complexity to facilitate fish passage through the structure. The boulder clusters should consist of 100 percent 12- to 18-inch streambed boulders (WSDOT Standard Specifications 9-03.11(2)). The void space within the boulder cluster will be filled with smaller streambed sediment during construction, and these smaller particles were not considered in the stability calculations or gradation in Table 9. The boulder clusters are stable at all flow events including the 500-year. Although boulders are not present in the existing conditions at this crossing, they are needed to force a meandering flow path through the structure in lieu of the tree root stabilized banks that occur upstream and downstream of the crossing. See Appendix C for results of the streambed sizing analysis.

The proposed streambed design, which has a proposed D_{50} equal to 1 inch (See Table 9), will be helpful for larger fish that pass through longer reaches in search of upstream spawning habitat. For juvenile salmonids, the length of the proposed crossing is too long to pass through without added spots where they can rest. To address this need, the design includes a low-flow channel between meanders, which will create a meandering path that increases complexity by reducing the slope and velocity within the channel. This added complexity helps passage of fish at all stages of life. The minimum thickness of the streambed material within the proposed grading area is 3 feet to accommodate the potential calculated total scour amount contained in Section 7.

Table 9: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Proposed diameter (in)	Boulder Cluster diameter (in)
$\mathbf{D_{16}}$	0.03	0.1	13.0
$\mathbf{D_{50}}$	0.1	1.0	15.0
$\mathbf{D_{84}}$	0.6	2.0	17.0
$\mathbf{D_{95}}$	0.8	2.3	17.6
$\mathbf{D_{100}}$	1.3	2.5	18.0

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for Big Scandia Creek at SR 308 MP 0.94.

4.3.2.1 Design Concept

The channel design concept is a low-gradient pool-riffle channel. Channel complexity features for the SR 308 crossing are designed to provide habitat and allow for natural stream processes. The channel complexity features for this crossing include LWM in open channel areas on both sides of the proposed structure and boulder clusters within the structure for habitat (see Figure 53). LWM comprises wood structures (trunks) greater than 6 feet in length and greater than 6 inches in diameter. LWM, used appropriately within a channel, can provide bank protection and channel resilience, and can offer benefits for aquatic habitat. Habitat provided by LWM can help provide aquatic life shelter from predators and higher velocity water, hyporheic flows, cooler waters, and gravel and sediment retention.

The project will reconstruct 240 feet of channel, roughly 127 feet of which is expected to be within the new structure, if a culvert is constructed, leaving 113 feet of open channel area. A bridge design would increase the open channel length along the constructed reach. For this length of reconstructed channel, 8 key pieces, 28 total pieces, and 37.4 cubic feet of LWM are recommended per the 75th percentile from Fox and Bolton, 2007. To achieve the recommended volume of wood, the LWM would need to be up to 4 feet in diameter at breast height (DBH). Pieces this size would be difficult to obtain, difficult to construct, and excessive for this 12-foot-wide channel. For these reasons, the volume of proposed LWM is less than the Fox and Bolton recommendation at this site.

Key pieces will consist of self-ballasting logs that are 2.0 feet DBH and 20 feet to 30 feet long. Additional pieces in the 1.0-foot to 1.5-foot DBH size range will be included. These smaller pieces would move only during extreme events and may not move far even during high flows, because they are likely to rack against larger wood pieces. Anchoring is anticipated until stability calculations are completed during final design that indicate otherwise. Appendix F shows the recommended quantities of woody material for this channel. Figure 53 presents the approximate locations and orientation of the LWM if the structure is a culvert, while Figure 54 presents the approximate locations and orientation of the LWM if the structure is a bridge. The amount of LWM in both structure type scenarios meet the recommended number key pieces and total number of pieces set forth by Fox and Bolton. LWM stability and special design considerations should be evaluated at final design when the proposed structure type and geometry is known.

A low flow channel will be formed through the LWM which connects with the low flow channel formed between boulder clusters within the structure. Boulder clusters as well as LWM are designed to be immobile during low and medium flow events, which will help maintain the low flow channel after large flow events. The low flow channel will minimize the risk of fish stranding during low flow periods. Juvenile coho, steelhead, and cutthroat trout will all directly benefit from this improved habitat, as they spend at least one year in the stream before migrating to the Puget Sound. Preformed pools are not recommended for this site, as the low flow channel and channel complexity items create sufficient hydraulic diversity for fish passage.

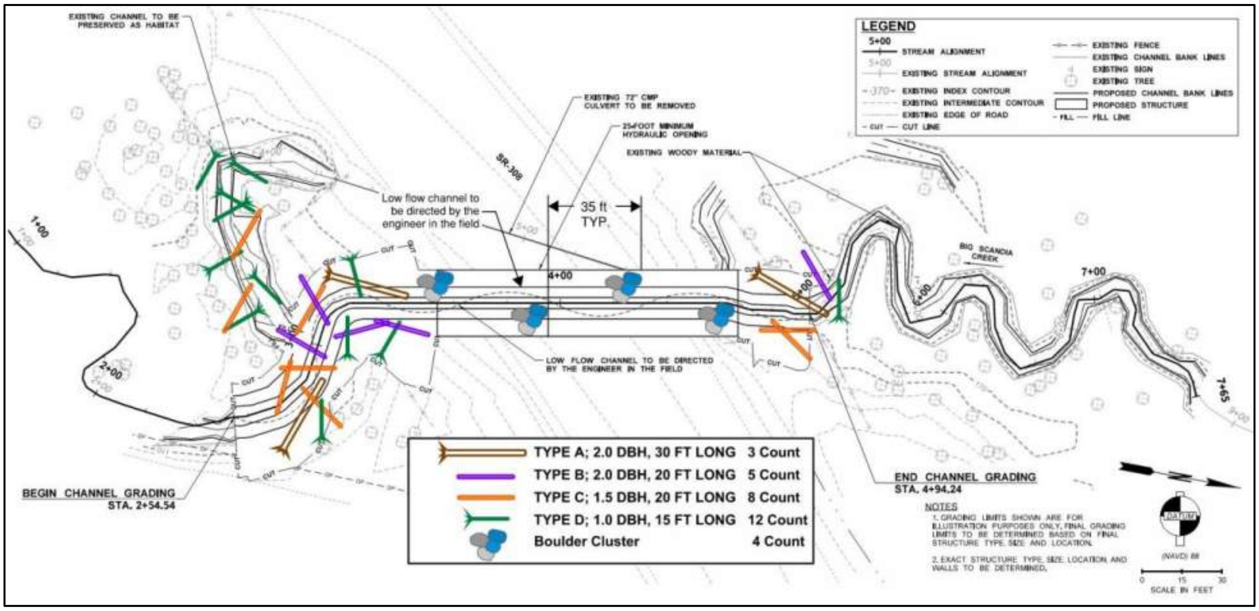


Figure 53: Conceptual layout of habitat complexity (Assumption structure type - Culvert)

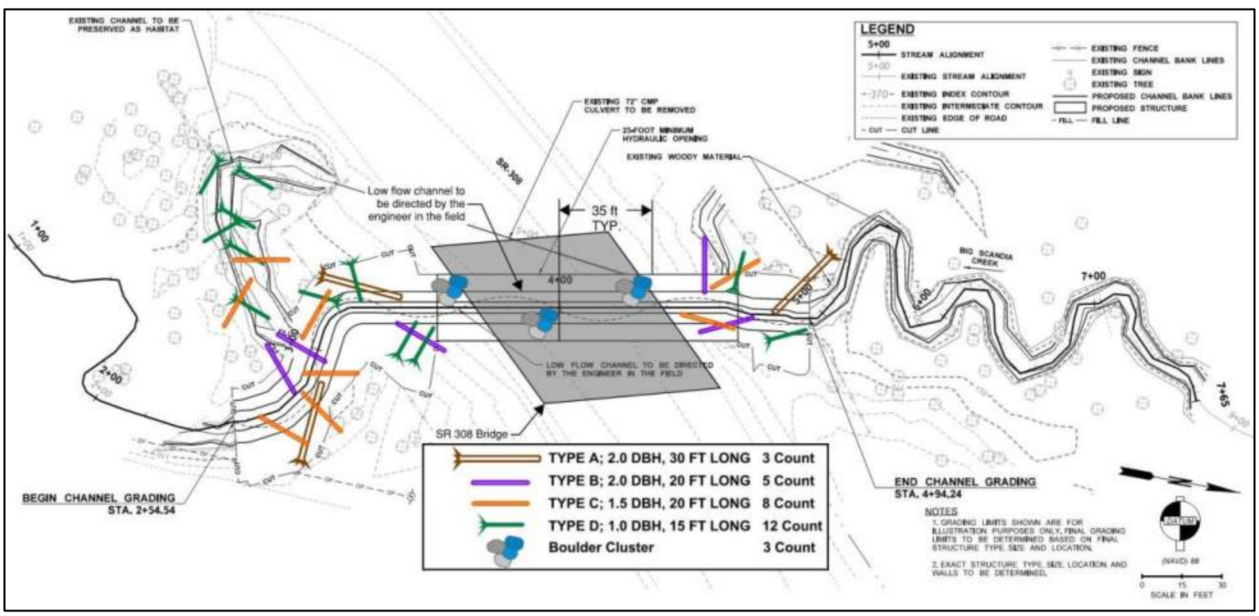


Figure 54: Conceptual layout of habitat complexity (Assumption structure type - Bridge)

A Conceptual Restoration Plan (CRP) will be developed at a later draft version of this PHD.

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed at final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 308 Big Scandia Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.3.1 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.14 (Aquaveo 2021).

3 scenarios were analyzed for determining stream characteristics for Big Scandia Creek with the SRH-2D models: (1) existing conditions with the 72-inch-diameter, 140-foot-long CMP culvert, (2) the natural conditions with a 12.5-foot-wide channel with roughly 25-foot meanders, and (3) proposed conditions with the proposed 25-foot minimum hydraulic opening.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The existing channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT on November 23, 2021. The survey data was supplemented with light detection and ranging (LiDAR) data (WSDNR 2018). The proposed channel geometry was developed from the proposed grading surface created by DEA. All survey and LiDAR information is referenced against the NAVD 88 vertical datum.

Topographic surface development for proposed condition site geometry used InRoads software to regrade the surface through the new crossing, extending roughly 50 feet upstream and 120 feet downstream of the existing SR 308 edge of pavement. A cross-section mimicking the channel geometry in the reference reach was applied uniformly through the reconstructed reach to model proposed conditions. An average grade of 0.6 percent was modeled between the selected upstream and downstream existing grade tie-in points. The topographic data was not updated to represent LWM or other habitat features during proposed conditions modeling. Instead, a surface roughness was selected that accounts for these features, as explained in Section 5.1.3.

5.1.2 Model Extent and Computational Mesh

The model extends from approximately 300 feet upstream of the existing SR 308 MP 0.94 inlet to approximately 300 feet downstream of the existing outlet, covering a total channel length of 730 feet (which includes the reference reach). The model limits were selected to ensure that, at steady state condition, the structure would not influence the hydraulics at the model inflow and outflow boundary conditions.

The model meshes have an element density that reflects the complexity of the site conditions. The existing conditions consist of 5,144 elements, the natural conditions consist of 5,392 elements and the proposed conditions model consist of 8,416 elements (see Figure 55, Figure 56, and Figure 57) and covers about 177,600 square feet. The meshes for all three conditions use quadrilateral elements in the channel and triangular elements over the remaining surface area. The meshes have an approximate vertex spacing of 3.5 feet along the channel banks and an approximate vertex spacing of 17 feet near the outer domain limits. Vertex spacing is 2 feet at the upstream boundary and 2 feet at the downstream boundary.

The vertex spacing varies through the channel since there are higher densities at the crossing and along channel bends for an increased level of detail at these locations. The SR 308 crossing in the proposed model has an average vertex spacing of 5.5 feet along the structure walls and 2.5 feet at the inlet and outlet.

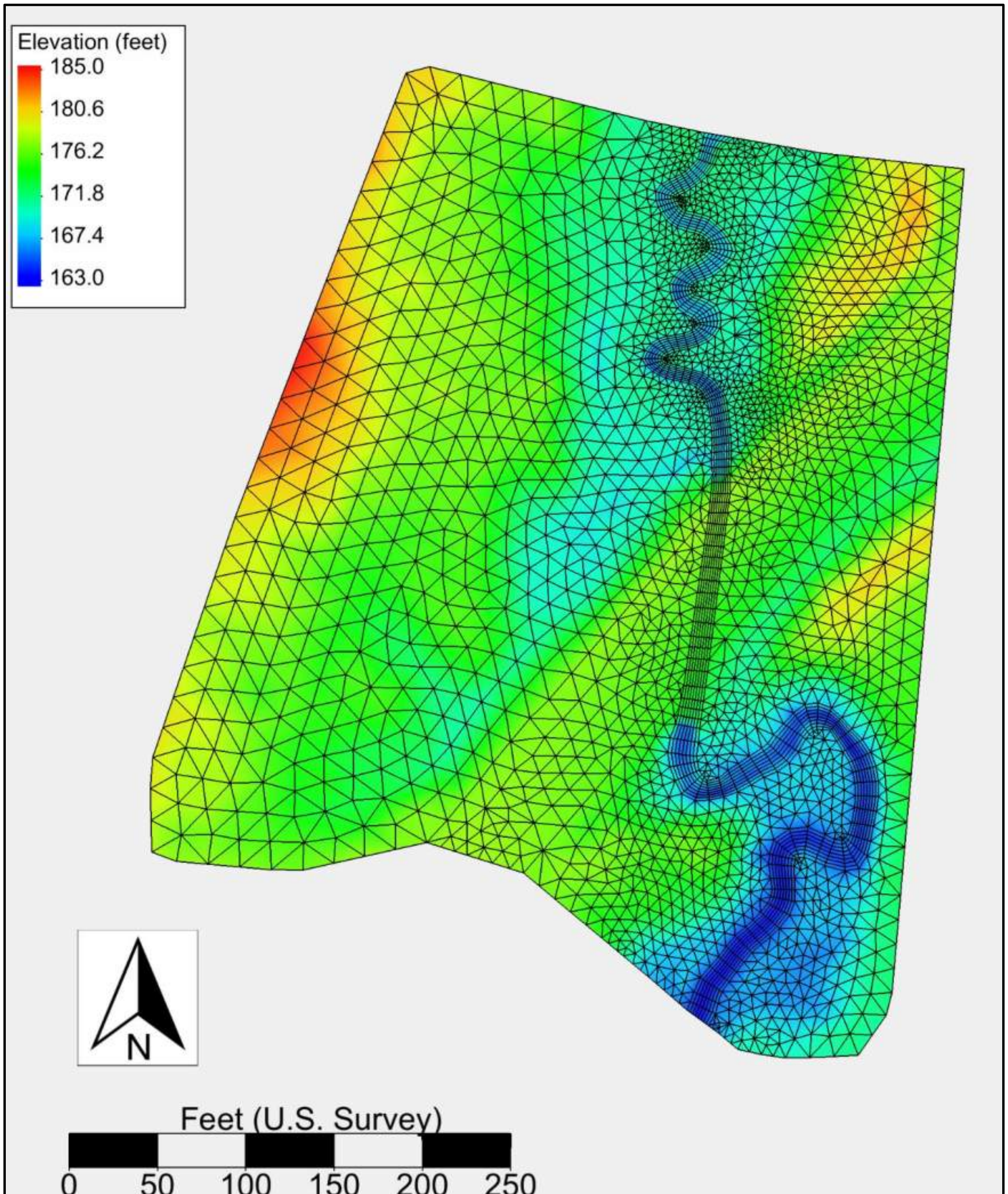


Figure 55: Existing-conditions computational mesh with underlying terrain

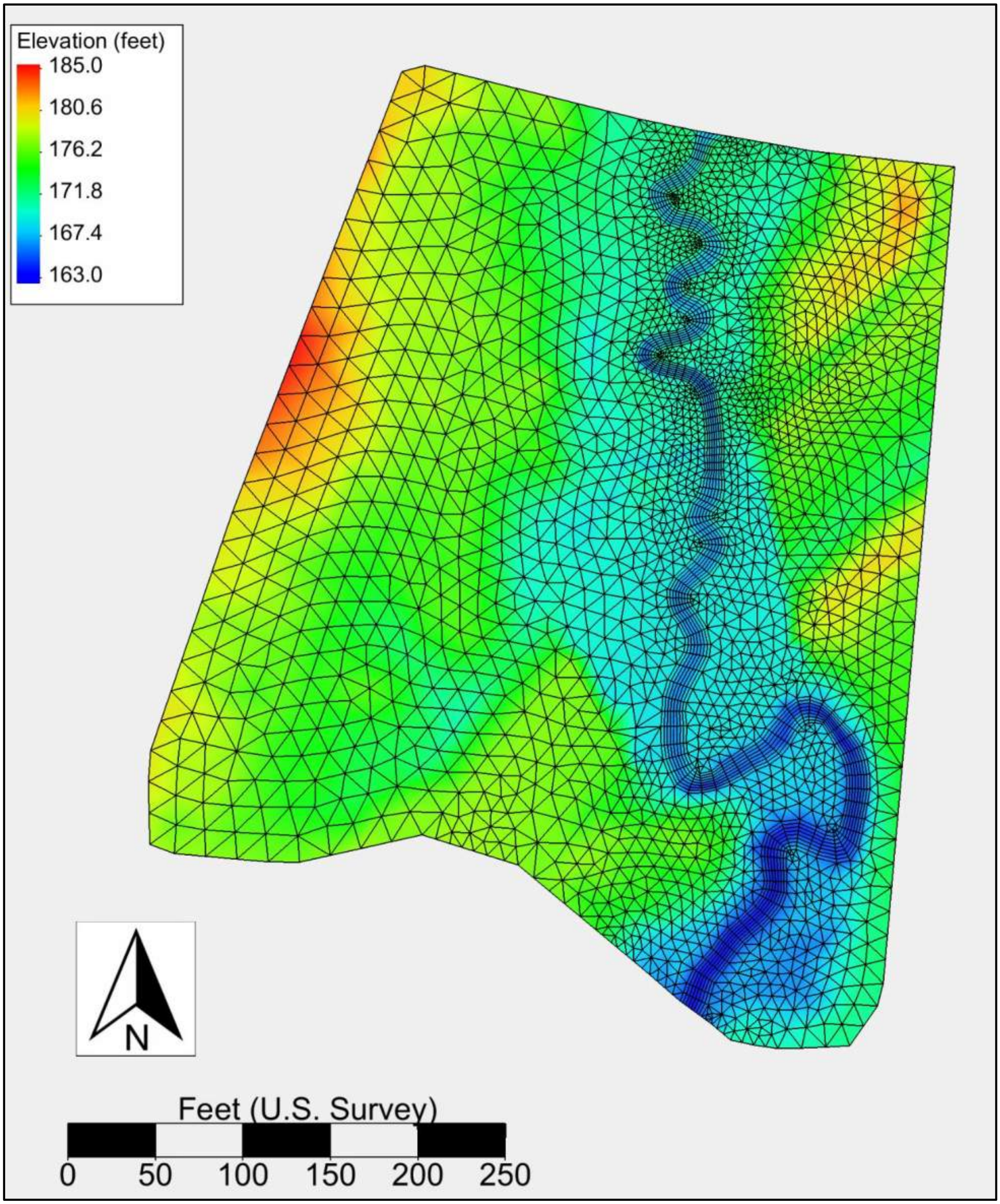


Figure 56: Natural-conditions computational mesh with underlying terrain

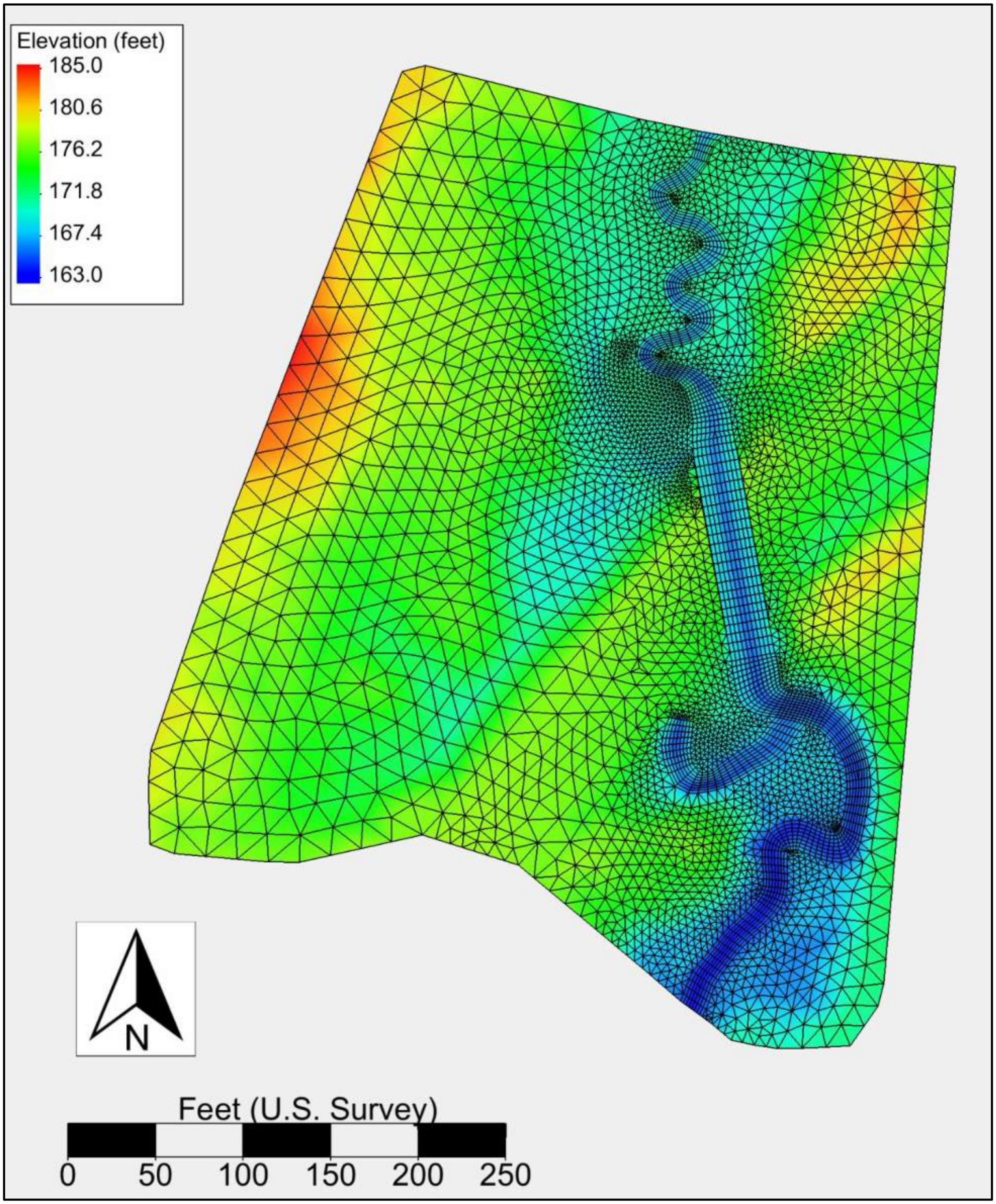


Figure 57: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

Table 10 lists the roughness coefficients used in the hydraulic modeling. These values were taken from Open Channel Hydraulics (Chow, 1959) and verified with field observations. The channel is well defined and flows within the channel are not hindered during existing conditions. A slight increase in typical sand bed channel roughness is due to the intermittent steps in the channel caused by wracking of small debris. It was observed during the site visits that these small debris drops are easily shifted during storm events. The overbank areas have higher roughness than the channel due to the existing vegetation (see Figure 58). For natural conditions, the roughness of the natural channel section mimics the existing conditions (see Figure 59). The proposed conditions roughness values of the reconstructed channel section were increased to account for the proposed LWM and boulder clusters (see Figure 60).

Table 10: Manning's n hydraulic roughness coefficient values used in the SRH-2D model for existing conditions (Chow, 1959)

Material	Manning's n
Floodplain	0.10
Channel	0.035
Banks	0.06
Road	0.025
LWM Channel*	0.08
Channel Meanders*	0.04

*Proposed only

Figure 58: Spatial distribution of existing-conditions roughness values in SRH-2D model

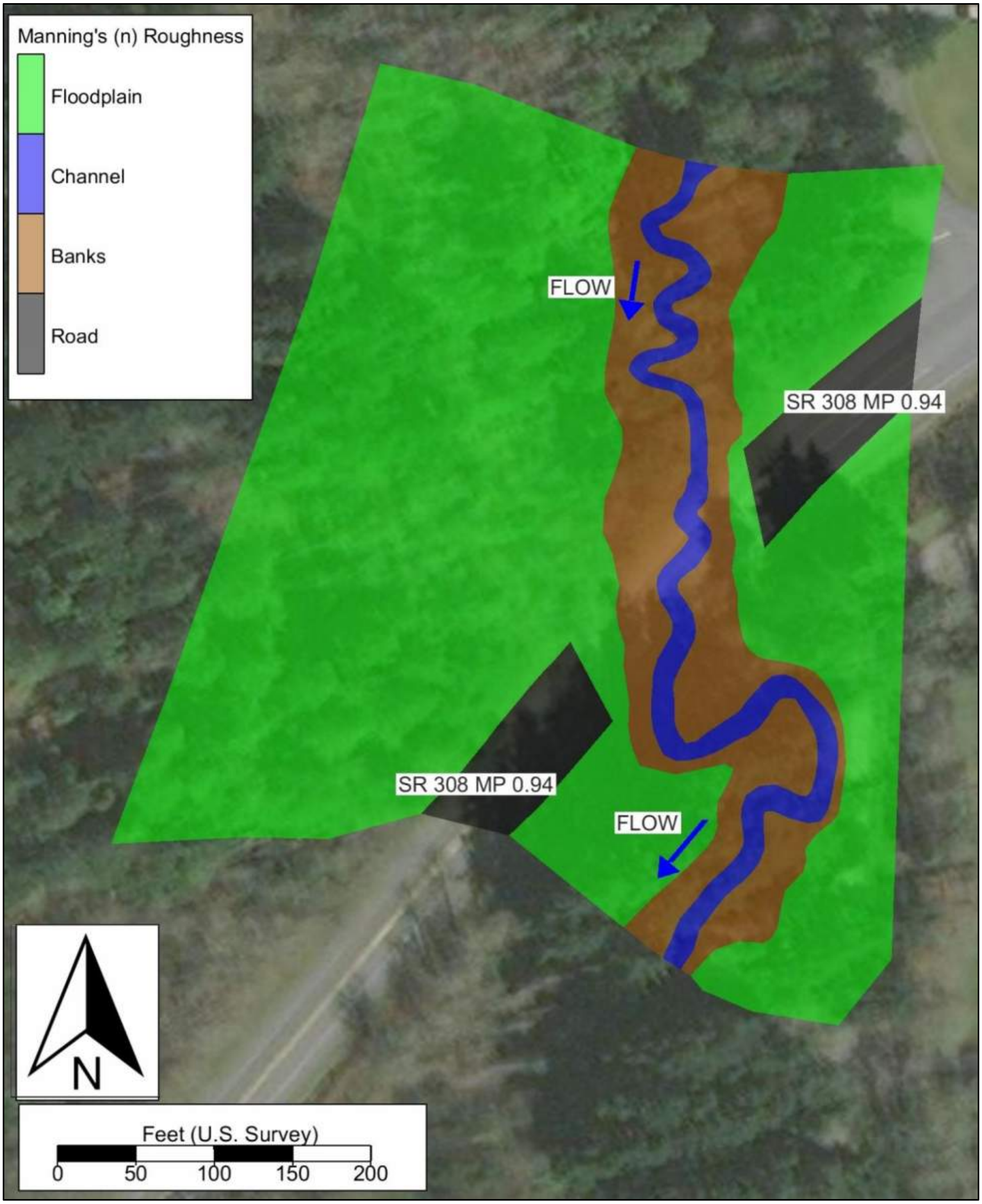


Figure 59: Spatial distribution of natural-conditions roughness values in SRH-2D model

For proposed conditions, the roughness of the proposed channel section is increased, because the section includes proposed LWM and boulder clusters. Figure 60 presents the roughness of the materials in proposed condition model.

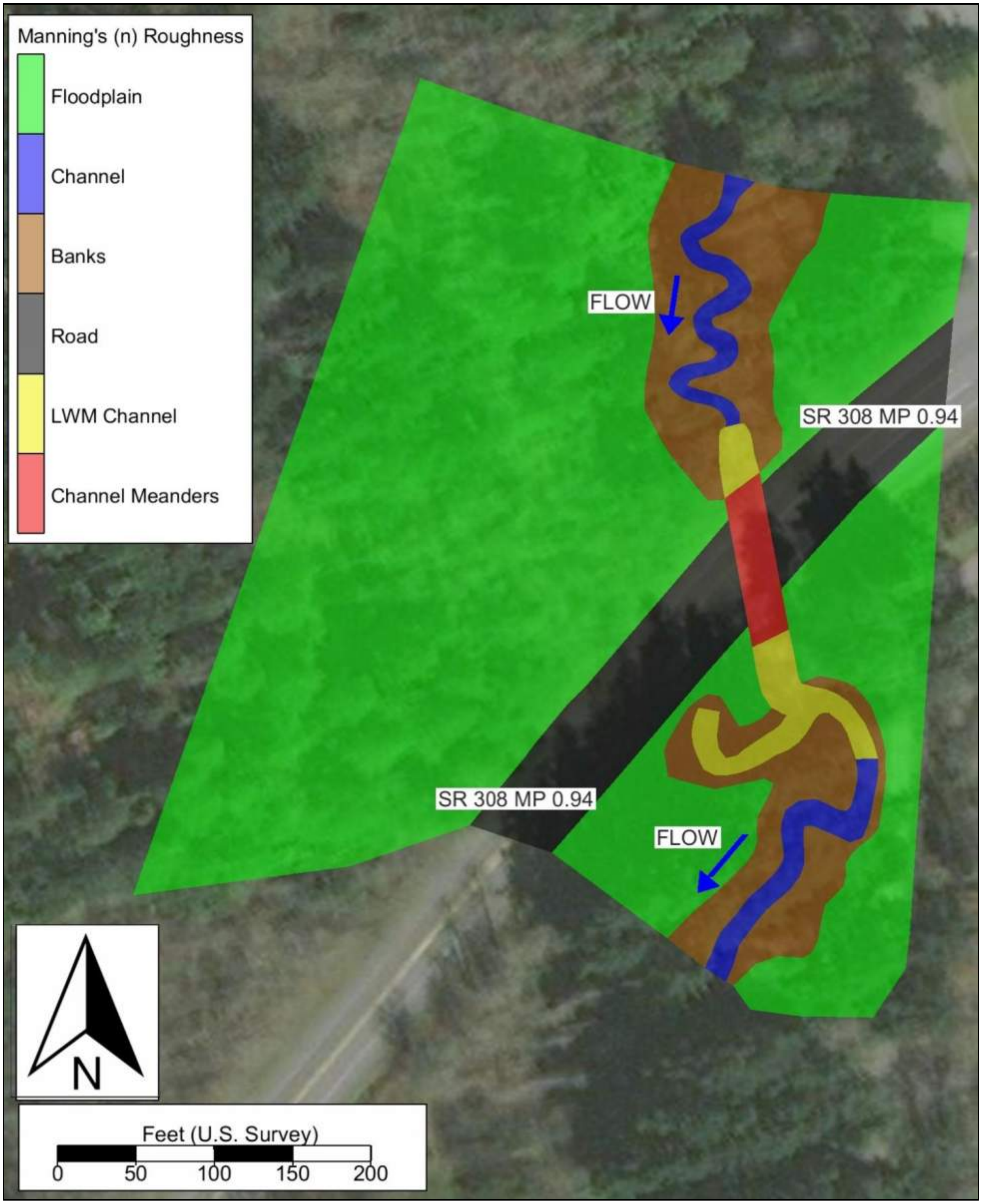


Figure 60: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

The SRH-2D model uses boundary conditions at locations where flow enters or leaves the model, including where the model simulates the culvert hydraulics by running the Federal

Highway Administration's HY-8 culvert analysis software, embedded in the Aquaveo SMS platform. The existing conditions model contains four boundary conditions: an inflow rate at the upstream limits, an inlet boundary and outlet boundary at the ends of the existing culvert for HY-8 (see Figure 61 for the HY-8 parameters), and a steady state, normal depth WSE at the downstream limits of the model. The proposed conditions model includes two boundary conditions: an inflow rate at the upstream limit and a WSE at the downstream limit. Figure 62 shows the rating curve for the downstream boundary condition. Figure 63, Figure 64, and Figure 65 show the locations of these boundaries in the existing, natural, and proposed conditions models, respectively.

The model specifies the upstream inflow boundary as a constant flow rate corresponding to the peak flow for the recurrence interval being modeled (i.e., peak flows equal to the 2-, 100-, 500-, and 2080 100-year flows).Table 6 in Section 3 provides these flow rates. The downstream outflow boundary was set for the normal water depth elevation using a composite Manning's n coefficient of 0.035 and a slope of 0.004 foot per foot that was measured from LiDAR. Both the inflow and outflow boundary conditions are the same for existing and proposed conditions. The inflow and outflow boundary conditions were set far enough away from the SR 308 MP 0.94 crossing so that they do not influence the hydraulic results at the project site. The model was run beyond the point where steady state was reached for all simulations (see Appendix I).

The existing conditions model used an additional pair of boundary condition arcs to simulate the existing 6-foot-diameter culvert. The SRH-2D model simulated the culvert hydraulics by running the Federal Highway Administration's HY-8 culvert analysis software as an embedded program within SMS. The paired-culvert boundary condition was used as an interface between SRH-2D and HY-8 within SMS. Culvert geometry, culvert type, and other relevant site data required for the HY-8 computations were compiled from the WSDOT survey and DEA site visits. Figure 63 shows the HY-8 input data for the existing culvert conditions.

For the natural and proposed conditions models the HY-8 parameters were not necessary because the channel and structure grading is embedded in the model surface (see Figure 64 and Figure 65). The natural and proposed conditions model used only upstream inflow and downstream outflow boundary conditions without HY-8.

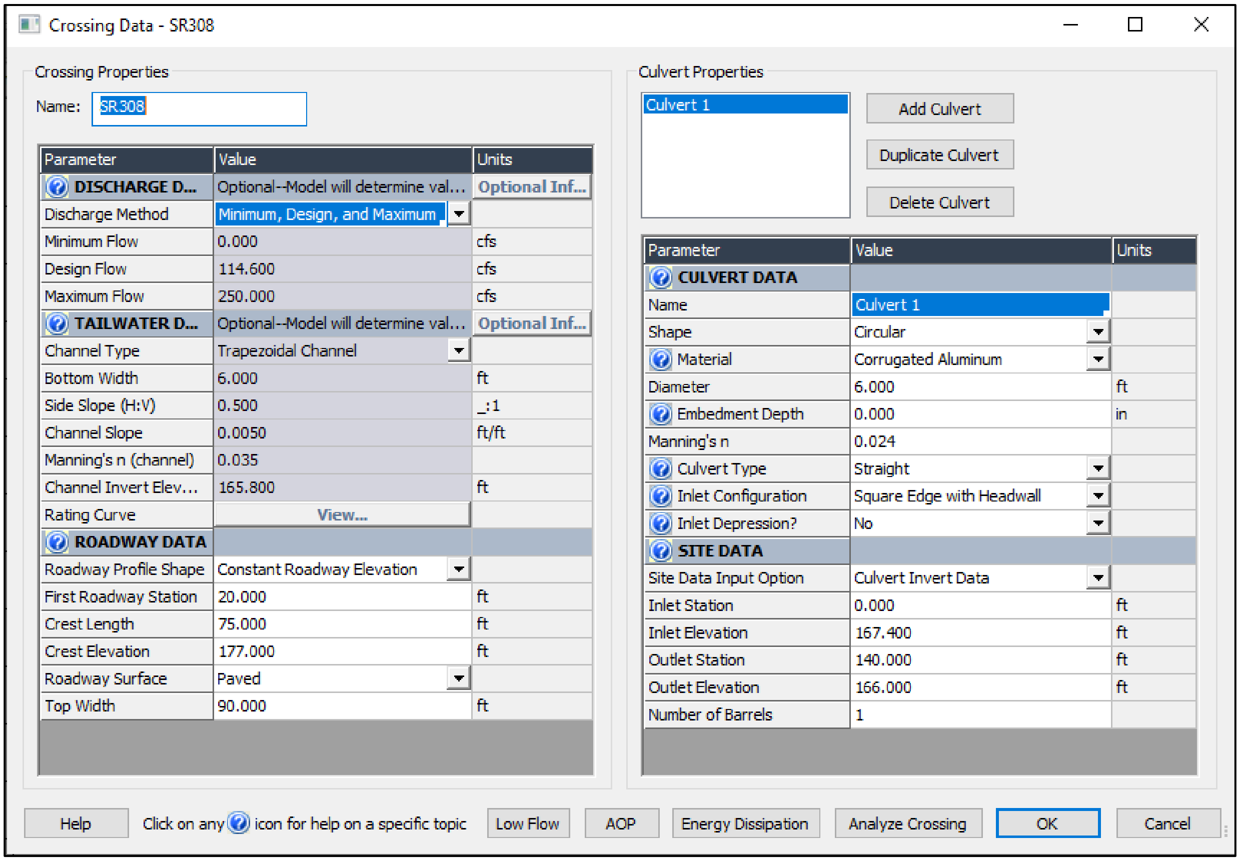


Figure 61: HY-8 culvert parameters

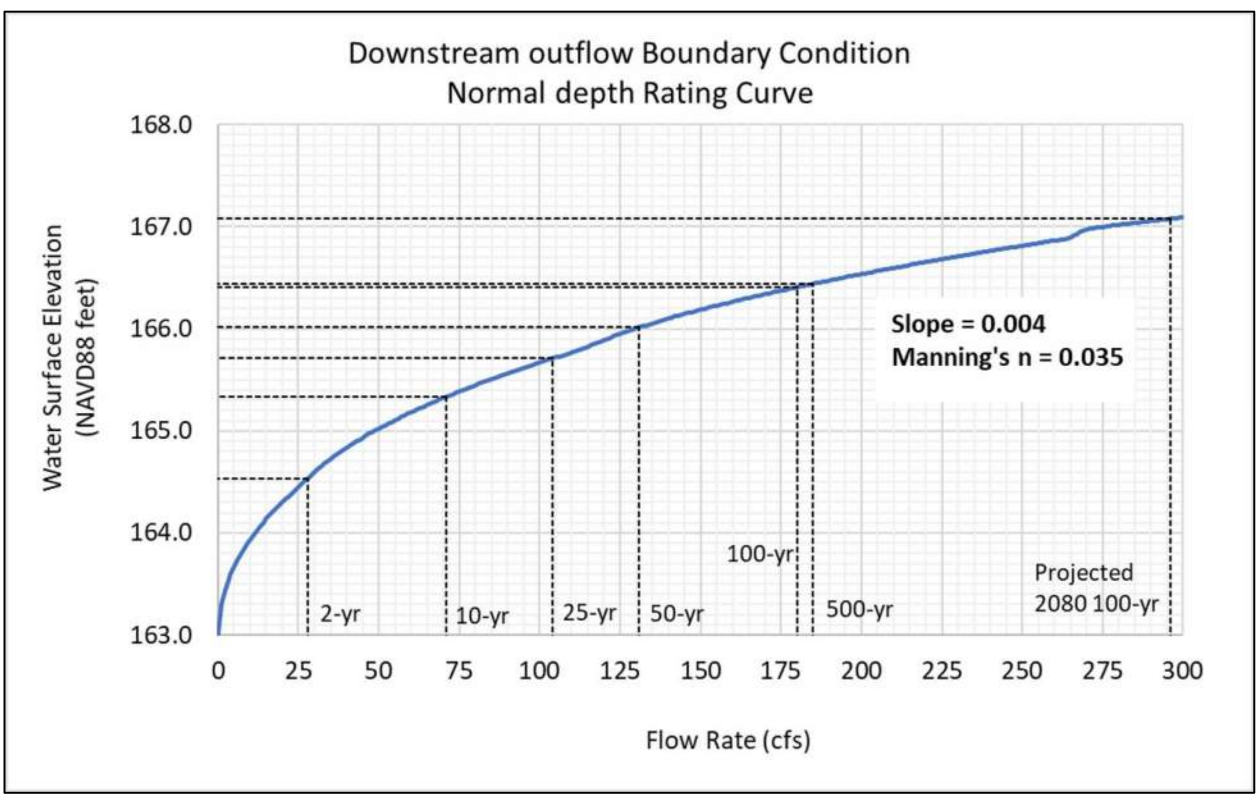


Figure 62: Downstream outflow boundary condition normal depth rating curve

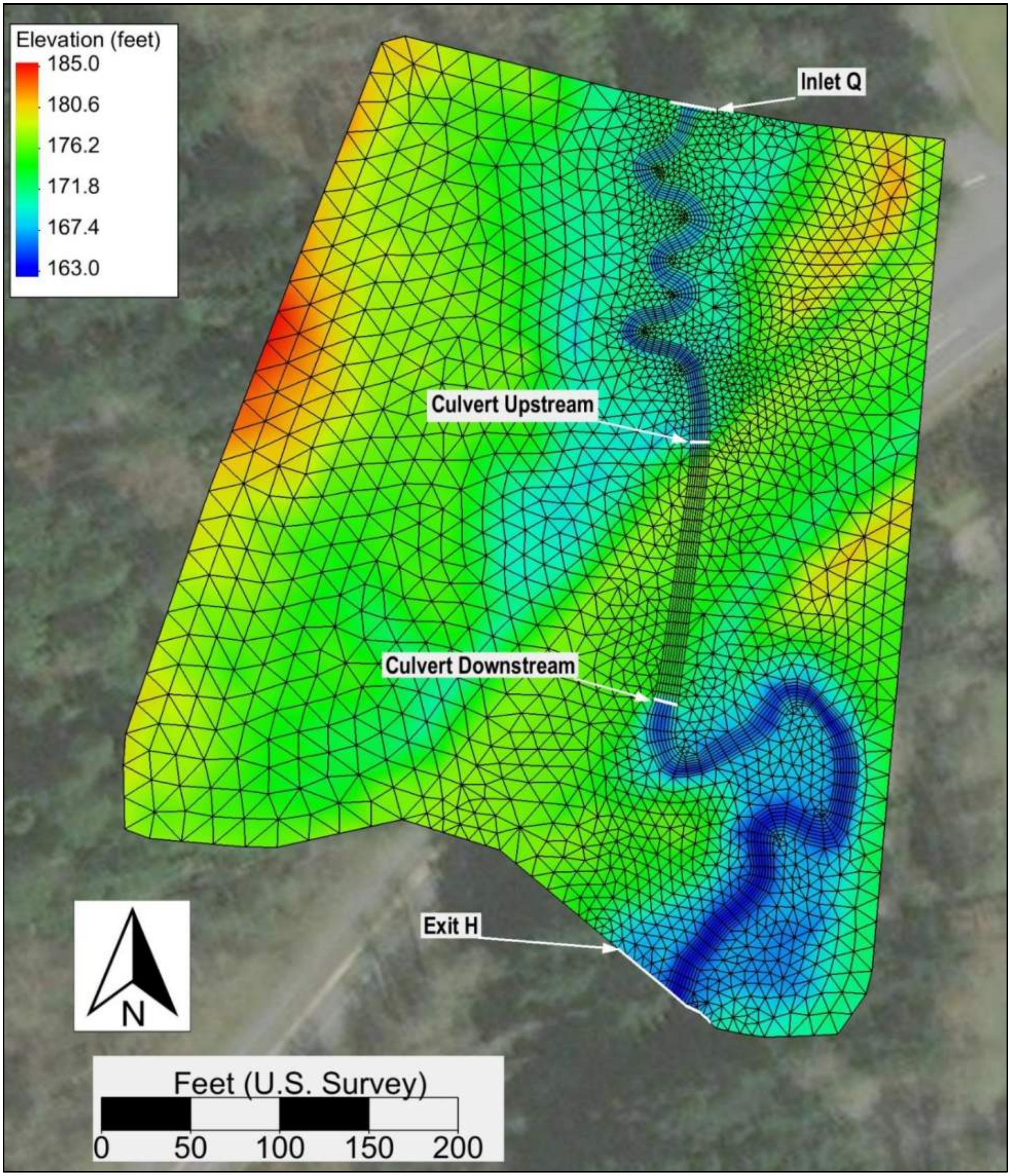


Figure 63: Existing-conditions boundary conditions

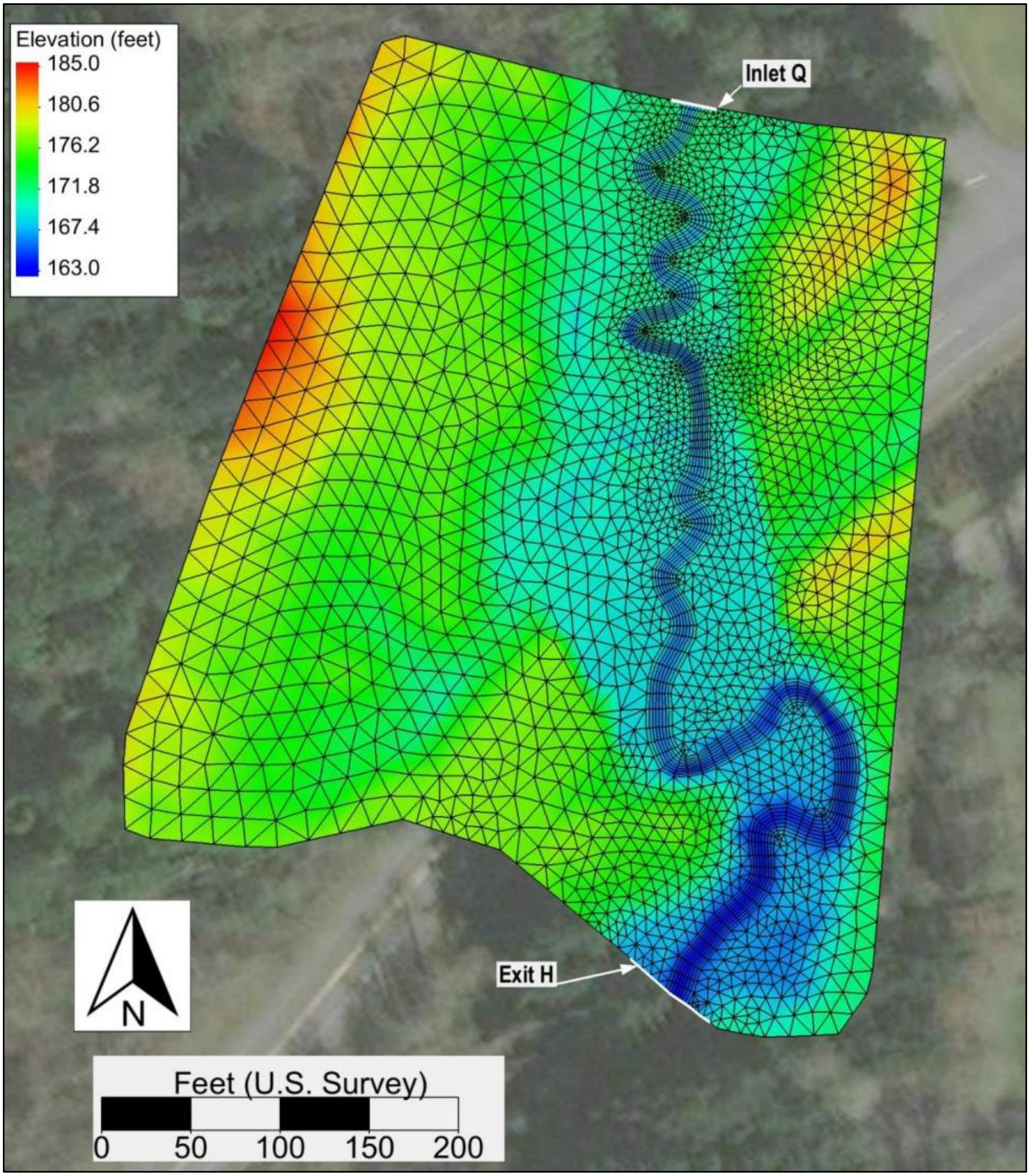


Figure 64: Natural conditions model - boundary conditions

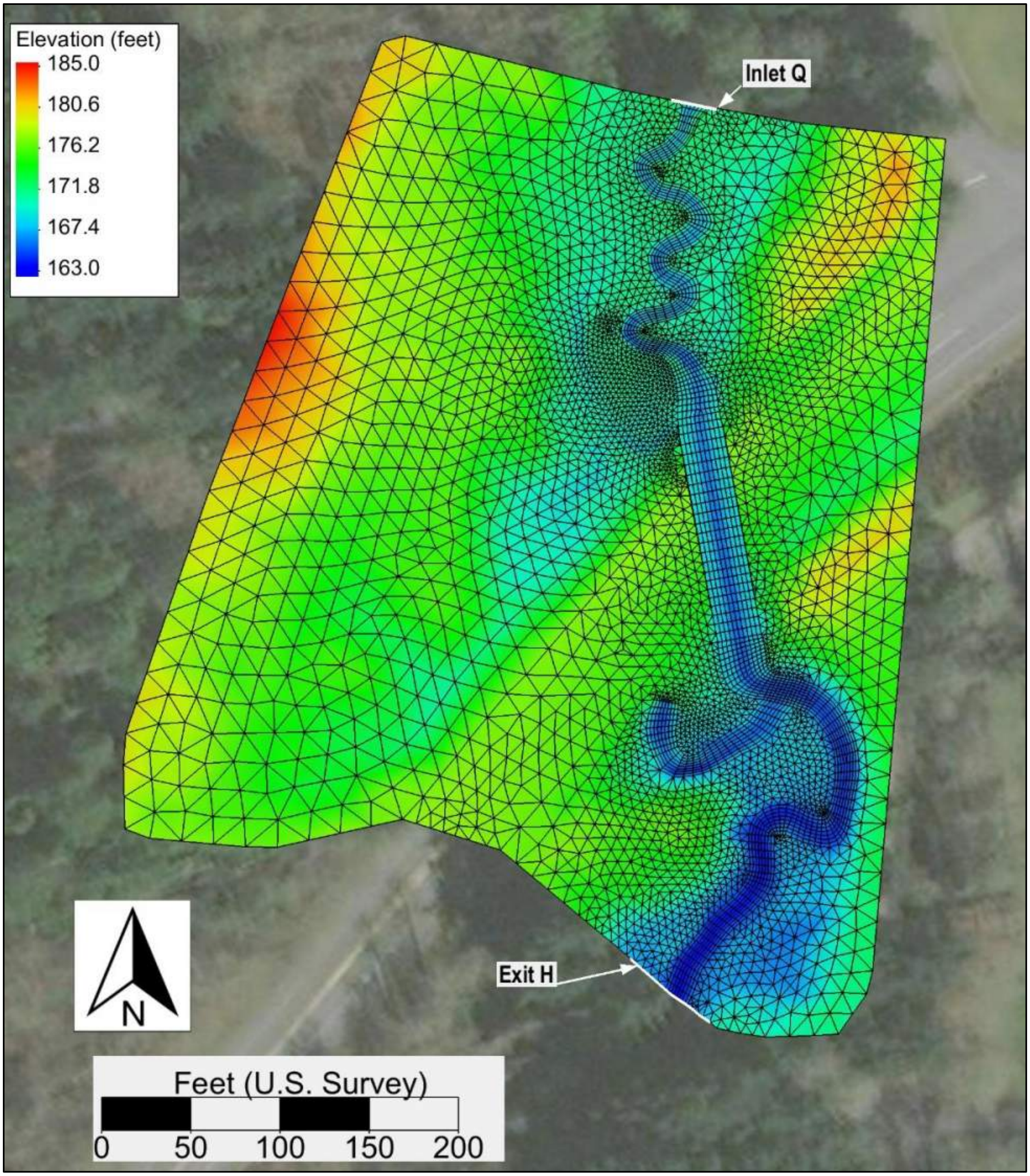


Figure 65: Proposed-conditions boundary conditions

5.1.5 Model Run Controls

The existing conditions and proposed conditions models ran long enough so no changes in the WSE at the boundaries were observed. The existing, natural, and proposed conditions models ran with default parameters for turbulence for 5 hours of simulation time with 0.5-second time steps, but typically achieved steady state conditions in less than 1 hour of simulation time.

Existing, natural, and proposed simulations began with a dry initial condition and event-specific flow values. Refer to Appendix I for model stability plots.

5.1.6 Model Assumptions and Limitations

The models assume that all the basin's flow enters the channel at the upstream boundary condition in a uniform condition, even though the runoff between SR 308 and the upstream boundary condition would enter the channel throughout this reach. No high-water marks or other indicators at the site were available for model calibration.

5.2 Existing Conditions

Figure 66 shows the locations of the cross-sections in the model where existing conditions data was sampled, and Table 11 presents the existing conditions model results at these cross sections. The hydraulic modeling of the existing culvert indicates that the culvert causes backwater at all flow events including the 2-year event. However, the backwater is not severe enough to overtop SR 308 even at the 500-year flow (see Figure 67). Figure 68 shows a typical cross-section of the existing channel within the backwatered area.

The hydraulic parameters shown in Table 11 follow typical patterns for a backwatered channel. Flow depths are elevated in the backwatered area while velocities and shear stresses are low in the upstream backwatered area. At the culvert outlet, velocities and shear stresses are high, but depth, velocity, and shear stress quickly return to values typical for a natural channel further downstream. Appendix H contains the spatial model results for these variables. The maximum modeled flow depths upstream of the crossing was 3.8 feet, 7.4 feet, and 7.5 feet for the 2-year, 100-year, and 500-year events respectively. Velocities ranged from 1.0 to 1.5 feet per second upstream of the crossing during the 2-year event, while the velocities for the 100-year and 500-year events have velocities less than 1 foot per second due to the backwater. Average shear stresses during all flow events were 0.1 pounds per square foot or less upstream of the crossing. Downstream of the crossing, depths ranged from 1.1 to 2.3 feet during the 2-year event and between 3.2 and 4.1 feet during the 100-year and 500-year events. Since the flow rate of the 500-year event is about 3 percent greater than the 100-year, the hydraulic results will be very similar between the two large flows. The velocities of the 2-year event ranged from 2.1 to 3.5 feet per second downstream of the crossing, while the 100-year and 500-year velocities ranged from 3.7 to 4.6 feet per second. Shear stresses downstream of the crossing for all flows ranged from 0.2 to 0.8 pounds per square foot.

It is notable that the 2-year flow does not fill the bankfull channel as would normally be expected. At this preliminary stage, our evaluation of flow rates is limited. The channel geometry indicates that actual flow rates may be higher than evaluated here. The current hydrologic analysis and hydraulic model results remain accurate ways to compare existing, natural, and proposed conditions results.

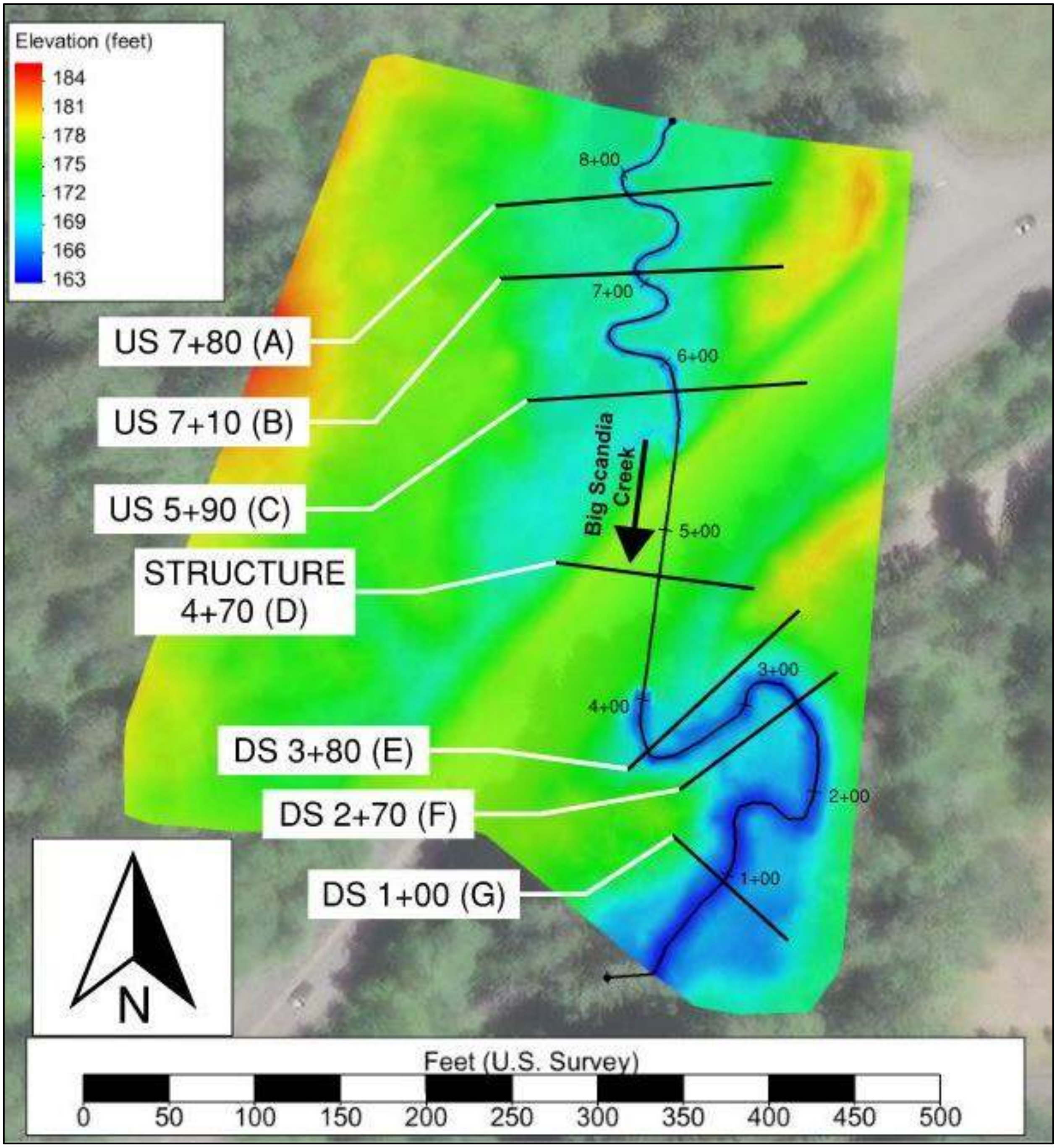


Figure 66: Locations of cross sections used for reporting results of existing conditions model

Table 11: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS STA 1+00 (G)	164.8	166.8	166.9
	DS STA 2+70 (F)	166.0	167.8	167.8
	DS STA 3+80 (E)	167.2	169.2	169.2
	STRUCTURE 4+70 (D)	NA	NA	NA
	US STA 5+90 (C)	169.5	173.3	173.4
	US STA 7+10 (B)	169.8	173.3	173.4
	US STA 7+80 (A)	169.9	173.4	173.5
Max depth (ft)	DS STA 1+00 (G)	1.5	3.5	3.6
	DS STA 2+70 (F)	2.3	4.0	4.1
	DS STA 3+80 (E)	1.1	3.2	3.2
	STRUCTURE 4+70 (D)	NA	NA	NA
	US STA 5+90 (C)	3.2	7.0	7.1
	US STA 7+10 (B)	3.8	7.4	7.5
	US STA 7+80 (A)	2.8	6.3	6.4
Average velocity (ft/s)	DS STA 1+00 (G)	2.1	3.7	3.7
	DS STA 2+70 (F)	2.6	4.6	4.6
	DS STA 3+80 (E)	3.5	4.4	4.4
	STRUCTURE 4+70 (D)	NA	NA	NA
	US STA 5+90 (C)	1.1	0.8	0.8
	US STA 7+10 (B)	1.0	0.5	0.5
	US STA 7+80 (A)	1.5	0.5	0.5
Average shear (lb/SF)	DS STA 1+00 (G)	0.2	0.4	0.4
	DS STA 2+70 (F)	0.3	0.8	0.8
	DS STA 3+80 (E)	0.7	0.6	0.6
	STRUCTURE 4+70 (D)	NA	NA	NA
	US STA 5+90 (C)	0.1	0.0	0.0
	US STA 7+10 (B)	0.0	0.0	0.0
	US STA 7+80 (A)	0.1	0.0	0.0

Note: Main channel extents were approximated by using 2-year event water surface top widths.
NA = Not applicable.

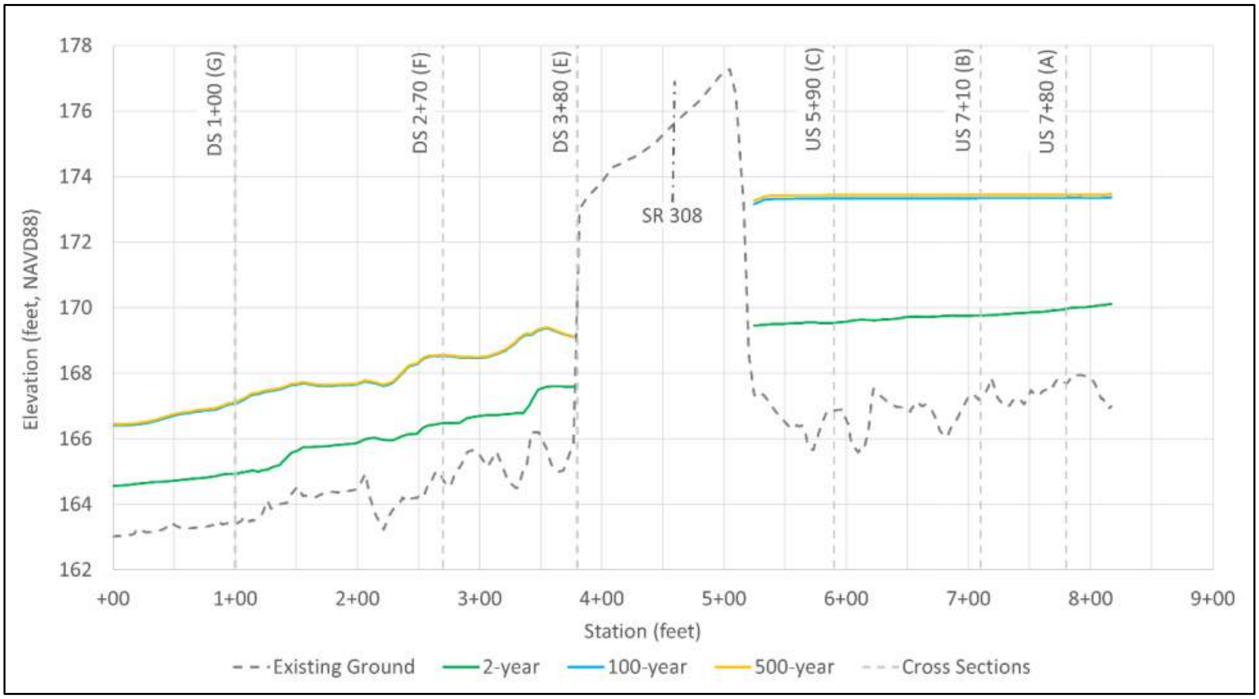


Figure 67: Existing-conditions water surface profiles

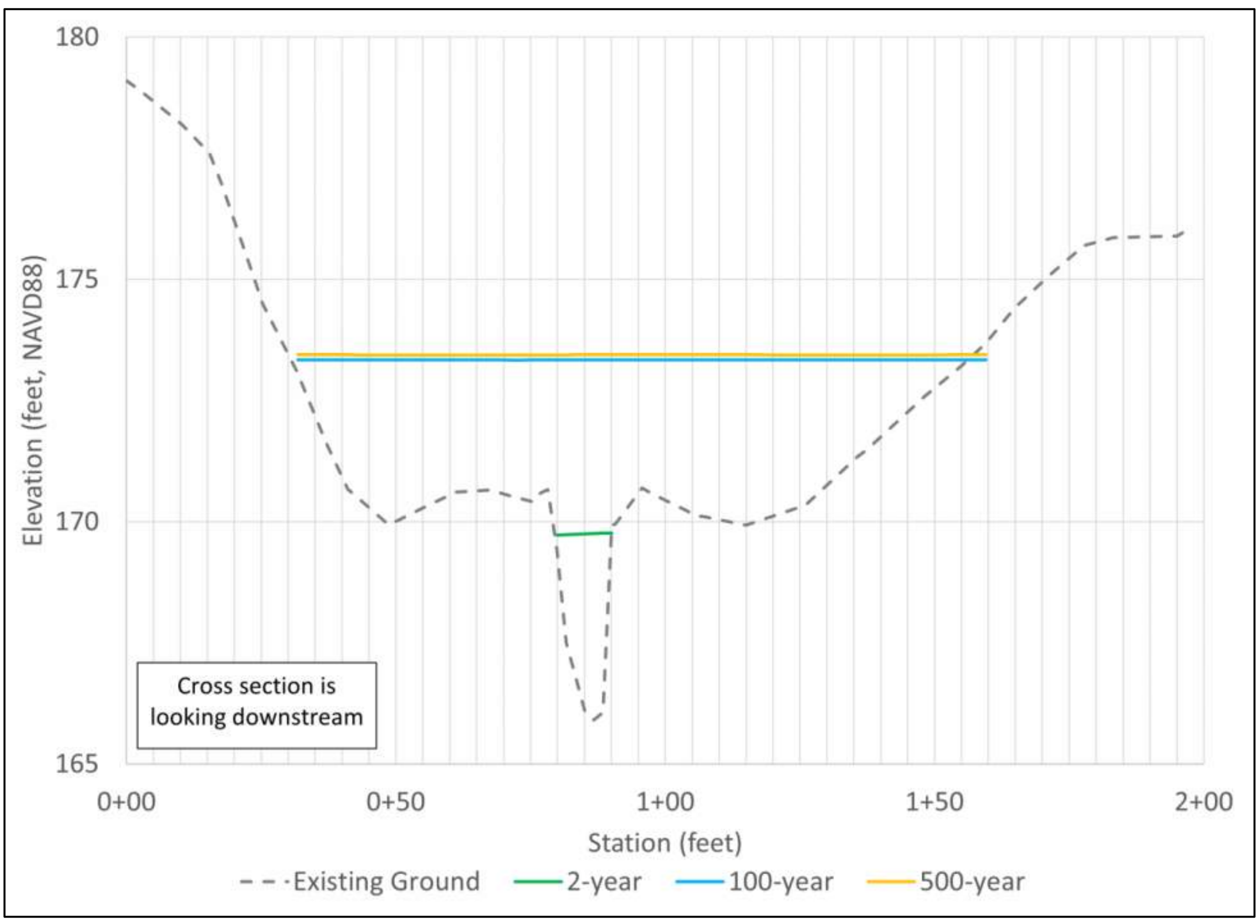


Figure 68: Typical upstream existing channel cross-section (STA 7+10)

Figure 69 shows the velocities during the 100-year event. The backwater pattern is evident with low velocities upstream of the culvert and more typical velocities downstream. Table 12 compares the main channel and overbank velocities during the 100-year event. The upstream main channel and overbank velocities are both low, whereas the downstream main channel velocities are distinctly higher than the overbank velocities.

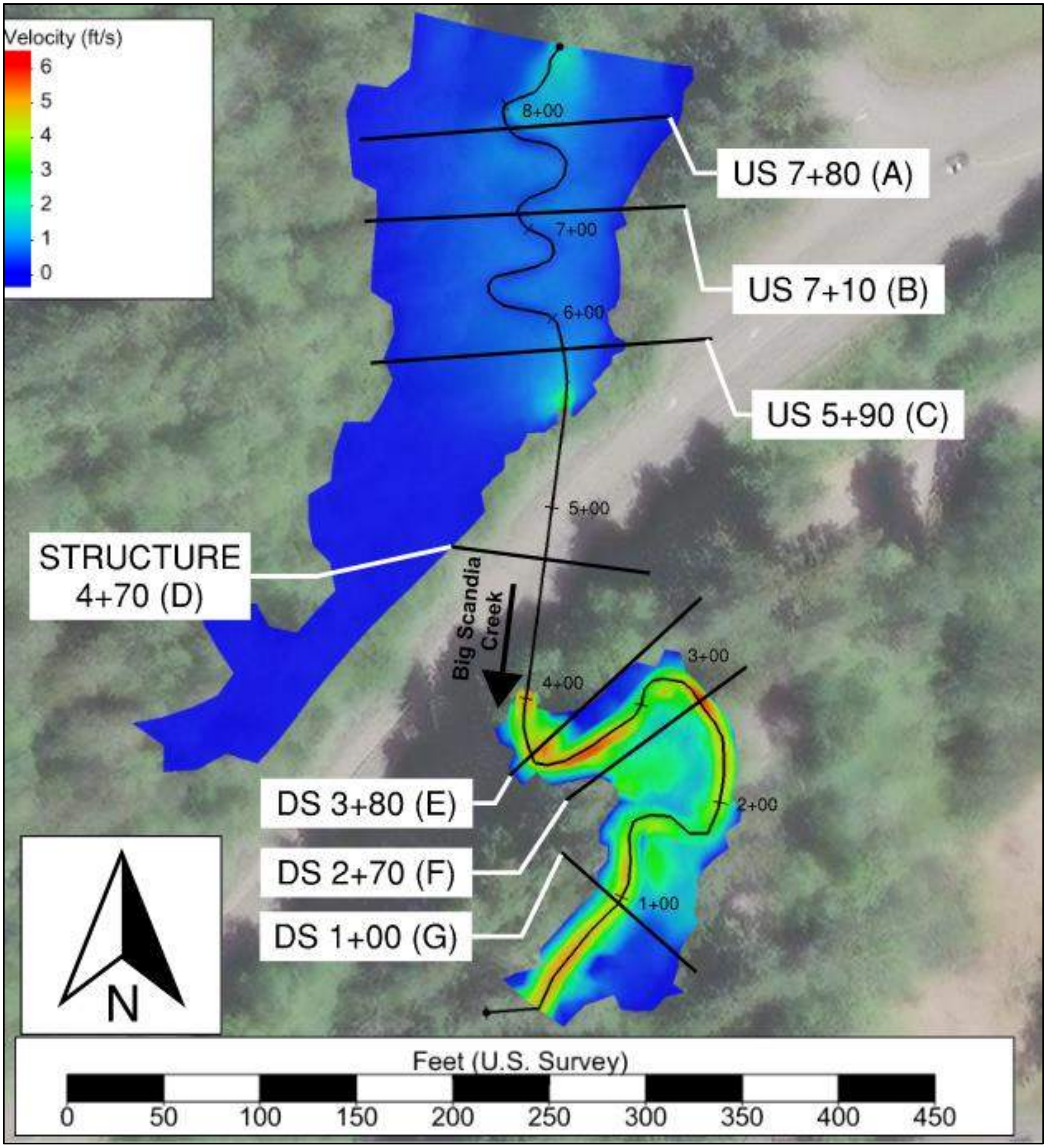


Figure 69: Existing-conditions 100-year velocity map with cross-section locations

Table 12: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS STA 1+00 (G)	0.5	3.7	1.7
DS STA 2+70 (F)	NA	4.6	2.0
DS STA 3+80 (E)	1.7	4.4	1.0
STRUCTURE 4+70 (D)	NA	NA	NA
US STA 5+90 (C)	0.4	0.8	0.4
US STA 7+10 (B)	0.6	0.5	0.4
US STA 7+80 (A)	0.6	0.5	0.3

[a]Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.
NA = Not applicable.

5.3 Natural Conditions

This channel is unconfined (FUR over 3.0) and requires an evaluation of natural conditions. The model approximated natural conditions by removing an 80-foot-wide swath of the road prism to incorporate a meandering channel that followed the existing channel slope. The 80-foot-wide swath used to emulate the natural conditions is 121 feet long when measured along the roadway centerline. The upstream meanders are highly sinuous in the culvert backwater area and the large curve in the channel just downstream of the crossing is influenced by Cox Road, so LiDAR data further from the site was used to determine typical meanders for this stream. The resulting alignment for the presumed natural channel is shown in Figure 70.

Figure 70 shows the cross-section locations where the hydraulic results in Table 13 were measured during the natural conditions analysis. The natural conditions channel at the SR 308 crossing conveys all flows between the 2-year and 500-year intervals without backwatering or overtopping the remaining roadway surface data in the model (see Figure 71). Figure 72 shows a typical cross-section of the channel in natural conditions under these flows.

Natural conditions depths range from about 1.3 feet to 3.2 feet within the modeled area during the 2-year event. At the higher 100-year and 500-year flows, maximum depths of 5.2 feet and 5.3 feet respectively were modeled. Velocities during the 2-year event ranged from 1.1 feet per second to 2.8 feet per second with elevated velocities during higher flows reaching a maximum of 5.9 feet per second. Similarly, shear stress ranged from 0.1 pounds per square foot to 0.3 pounds per square foot during a 2-year event and increased up to 1.1 pounds per square foot at higher flows. These values are typical for channels of this size and slope. Appendix H contains the spatial hydraulic model results for natural conditions.

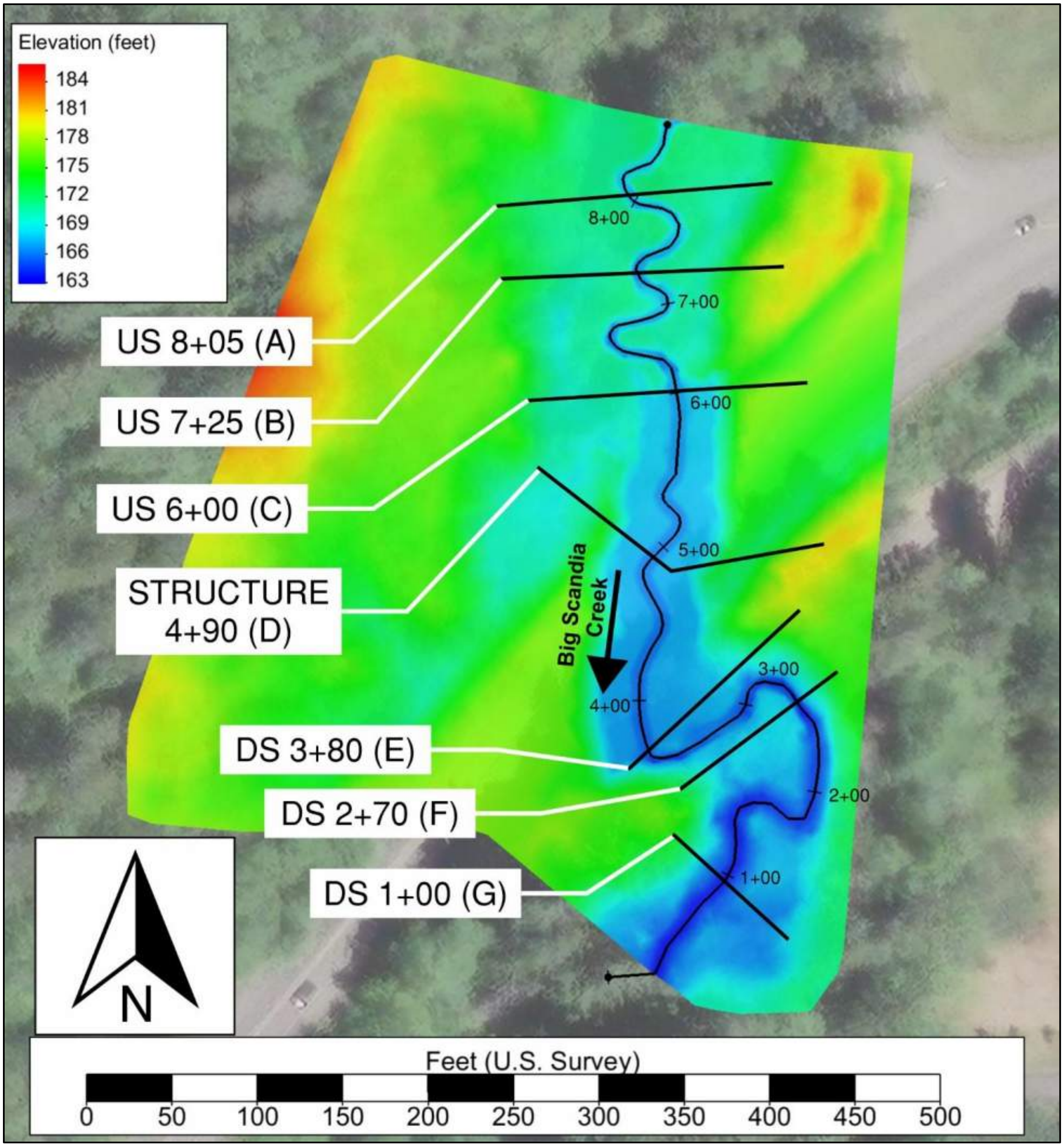


Figure 70: Locations of cross sections used for reporting results for the natural conditions model

Table 13: Average main channel hydraulic results for natural conditions

Hydraulic parameter	Cross section	2-year	100-year	2080 100-year	500-year
Average WSE (ft)	DS 1+00 (G)	164.8	166.8	167.5	166.8
	DS 2+70 (F)	166.0	167.7	168.4	167.8
	DS 3+80 (E)	167.0	168.7	169.2	168.7
	Structure 4+90 (D)	167.2	168.8	169.3	168.8
	US 6+00 (C)	167.6	168.8	169.4	168.8
	US 7+25 (B)	169.1	171.1	171.5	171.2
	US 8+05 (A)	169.5	171.4	171.9	171.5
Max depth (ft)	DS 1+00 (G)	1.5	3.5	4.2	3.5
	DS 2+70 (F)	2.3	3.9	4.7	4.0
	DS 3+80 (E)	1.9	3.6	4.1	3.6
	Structure 4+90 (D)	1.4	3.1	3.6	3.1
	US 6+00 (C)	1.3	2.5	3.2	2.6
	US 7+25 (B)	3.2	5.2	5.6	5.3
	US 8+05 (A)	2.4	4.3	4.8	4.4
Average velocity (ft/s)	DS 1+00 (G)	2.1	3.9	4.1	3.9
	DS 2+70 (F)	2.6	4.4	4.0	4.3
	DS 3+80 (E)	1.1	0.8	0.9	0.8
	Structure 4+90 (D)	1.9	2.4	3.0	2.4
	US 6+00 (C)	2.8	5.8	5.9	5.8
	US 7+25 (B)	1.3	2.1	2.1	2.1
	US 8+05 (A)	1.8	2.3	2.1	2.3
Average shear (lb/sf)	DS 1+00 (G)	0.2	0.4	0.4	0.4
	DS 2+70 (F)	0.3	0.7	0.5	0.7
	DS 3+80 (E)	0.1	0.0	0.0	0.0
	Structure 4+90 (D)	0.2	0.2	0.3	0.2
	US 6+00 (C)	0.3	1.1	1.0	1.1
	US 7+25 (B)	0.1	0.1	0.1	0.1
	US 8+05 (A)	0.2	0.2	0.1	0.2

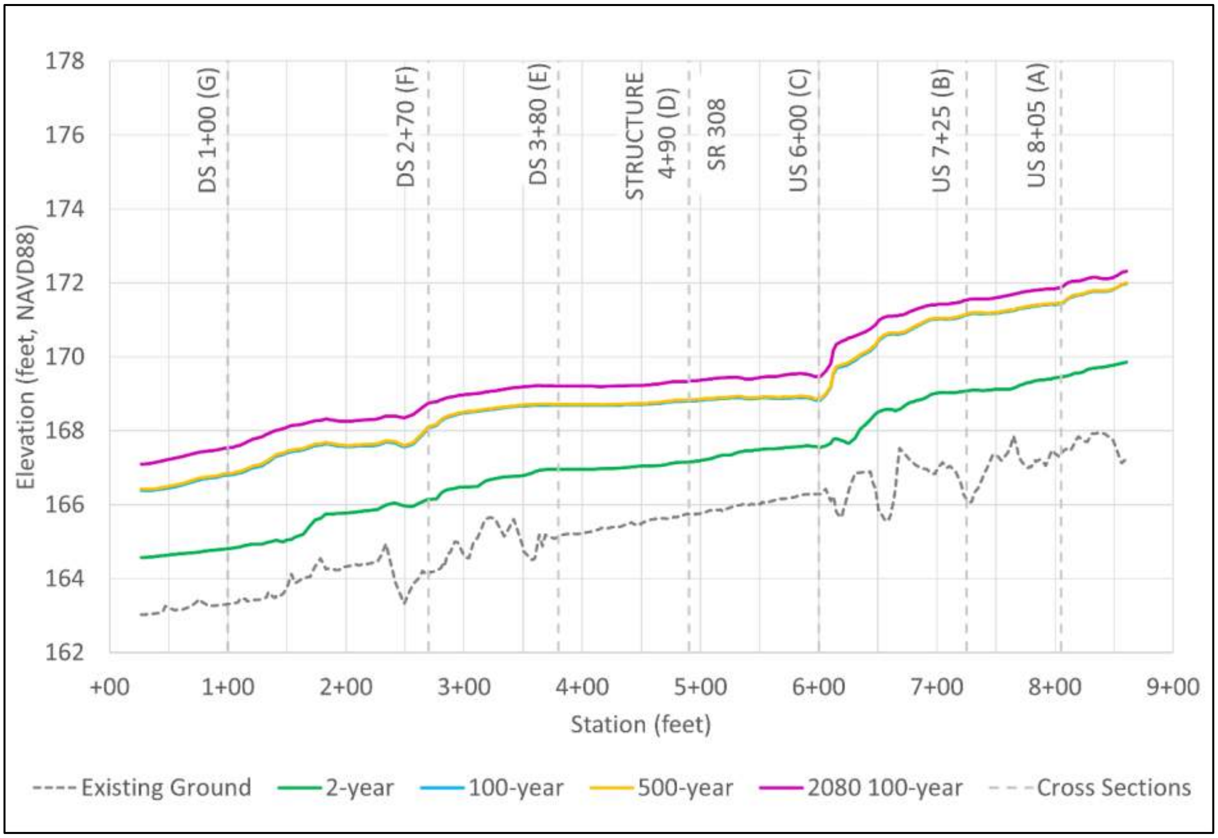


Figure 71: Natural-conditions water surface profiles

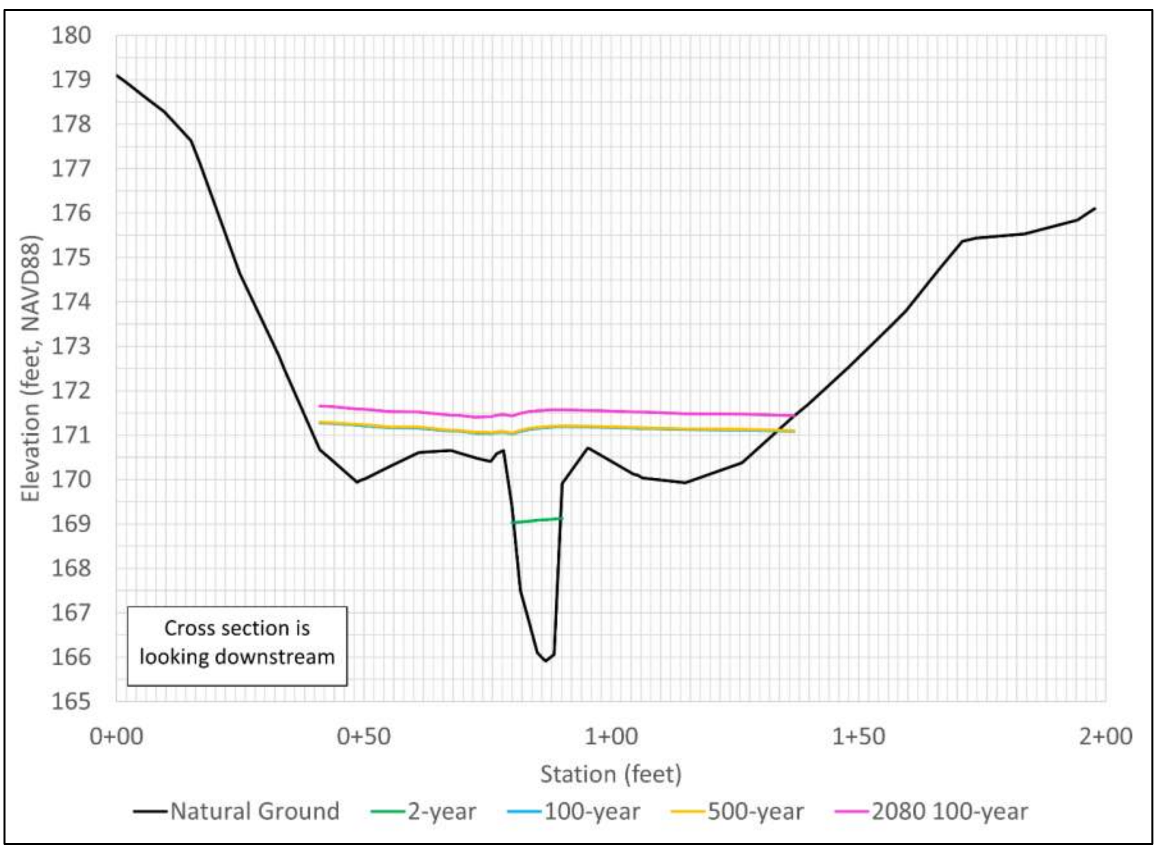


Figure 72: Typical upstream natural channel cross-section (STA 7+25)

The natural conditions model shows that high flows utilize the floodplain benches on both sides of the channel, as can be seen in Figure 73. The velocity in the overbank areas is generally lower than within the main channel as shown in Table 14. Hydraulic analysis of the 2080 100-year flow shows that velocities in the channel and on the overbanks are expected to increase by a maximum of 1.1 feet per second.

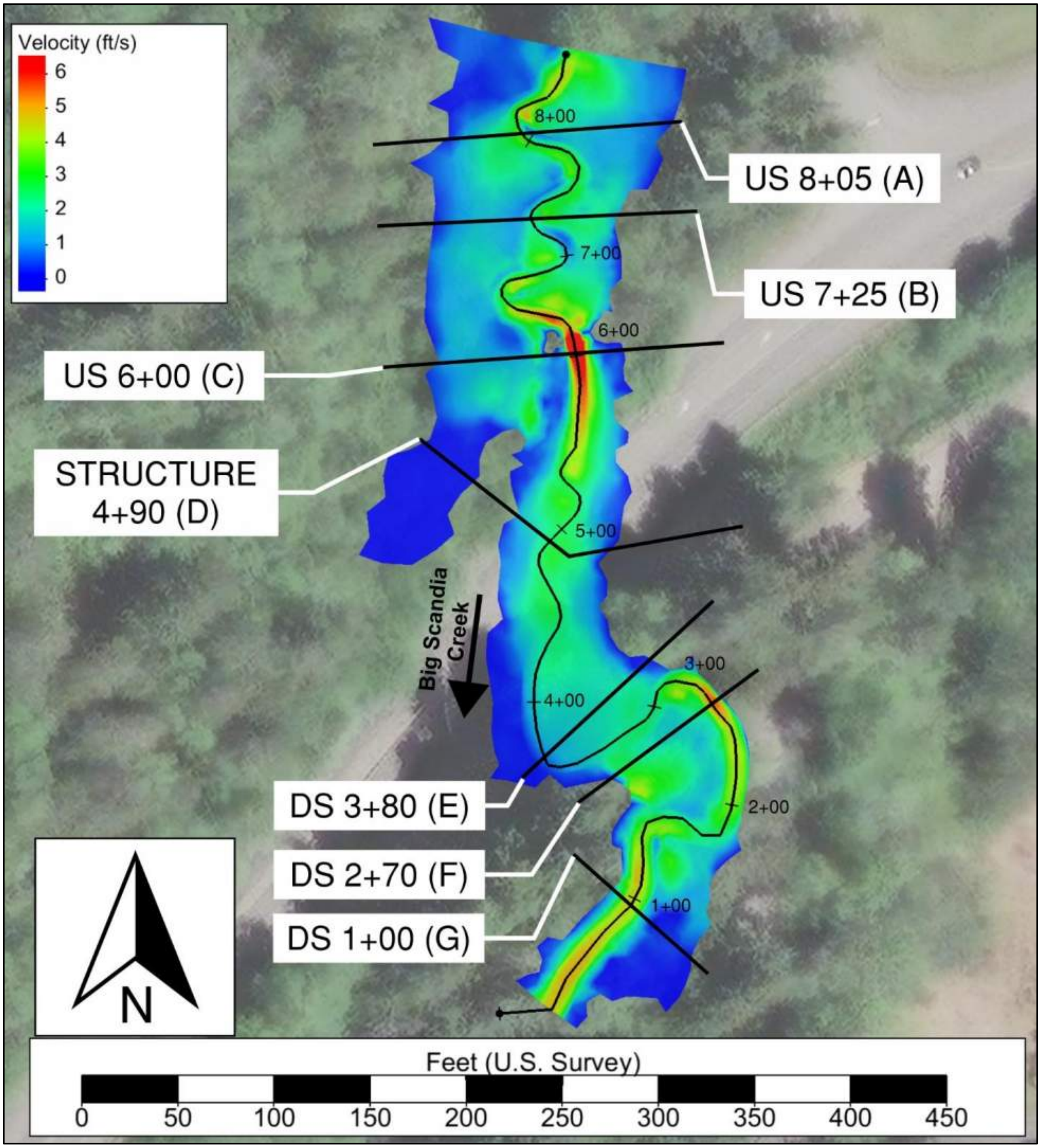


Figure 73: Natural-conditions 100-year velocity map with cross-section locations

Table 14: Natural-conditions average channel and floodplains velocities

Cross-section location	Q100 Average Velocities (ft/s)			2080 Q100 Average Velocities (ft/s)		
	LOB*	Main Channel	ROB*	LOB*	Main Channel	ROB*
DS 1+00 (G)	0.4	3.9	1.8	1.0	4.1	2.0
DS 2+70 (F)	NA	4.4	1.9	NA	4.0	3.0
DS 3+80 (E)	1.4	0.8	0.1	1.9	0.9	0.2
Structure 4+90 (D)	1.8	2.4	0.5	2.4	3.0	0.6
US 6+00 (C)	0.9	5.8	1.1	1.1	5.9	2.2
US 7+25 (B)	2.3	2.1	1.0	2.6	2.1	1.5
US 8+05 (A)	1.2	2.3	1.6	1.7	2.1	1.5

[a]Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.

5.4 Proposed Conditions: 25-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width unless otherwise specified. See Section 4.2.2 for a description of how the minimum hydraulic width was determined.

The proposed conditions model replaces the existing SR 308 culvert with a 25-foot hydraulic opening modeled as an open channel cut through the SR 308 embankment. This approach does not use an HY-8 culvert representation at the crossing, because the intent is to simulate stream functions within the structure. The proposed conditions model includes 93 feet of proposed open channel grading upstream of the structure and 20 feet of proposed grading downstream of the structure. Figure 74 shows the locations of the cross-sections where the hydraulic results contained in Table 15 were measured. Appendix H contains the spatial distribution of the proposed hydraulic results.

Figure 75 shows the existing and proposed ground profiles as well as the proposed water surface elevations for each modeled flow event. As seen in the figure, backwater conditions observed in the existing model are eliminated. The 100-year flow depth within the channel through the structure is roughly 3.9 feet, which is similar to the upstream and downstream depths, which are 3.8 and 3.9 feet, respectively (see Table 15). Floodplain velocities are similar upstream, downstream, and through the crossing as they all contain areas ranging from 0 to 3.5 feet per second.

Velocities during the 2-year flow event along the channel profile range from 1.2 feet per second to 2.1 feet per second. Within the proposed grading velocities range from 1.8 feet per second to 1.9 feet per second. During the 100-year and 500-year flow events, velocities increase up to 4.8 feet per second. Velocities within the structure are similar to velocities in the open channel areas during all flows. It is expected that over time, the channel will naturally adjust, and that depth and velocities will continue to be similar the upstream and downstream values.

Shear stresses within the structure are slightly lower than within the downstream reaches (see Table 15). The increased roughness adjacent to the crossing due to the presence of LWM creates greater flow depths and consequently greater shear. These results support the selection of the proposed streambed material as well as inclusion of boulder clusters.

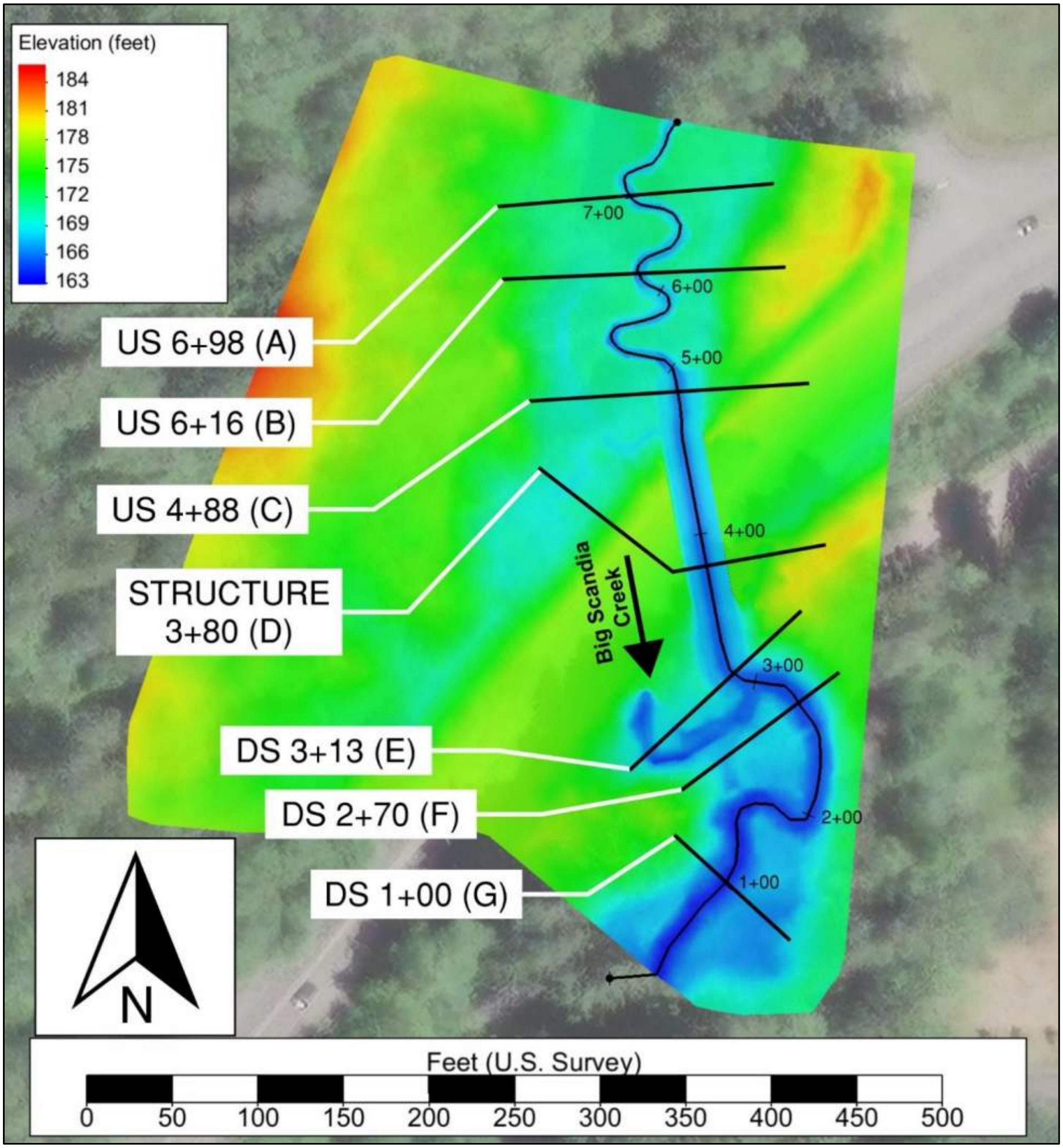


Figure 74: Locations of cross sections used for reporting results for proposed conditions model

Table 15: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS 1+00 (G)	164.8	166.8	167.6	166.8
	DS 2+70 (F)	166.3	168.1	168.7	168.2
	DS 3+13 (E)	166.6	168.5	169.1	168.5
	Structure 3+80 (D)	166.9	168.9	169.6	168.9
	US 4+88 (C)	167.7	169.5	170.4	169.6
	US 6+16 (B)	169.1	171.1	171.6	171.2
	US 6+98 (A)	169.5	171.4	171.9	171.5
Max depth (ft)	DS 1+00 (G)	1.5	3.5	4.3	3.5
	DS 2+70 (F)	2.0	3.8	4.4	3.8
	DS 3+13 (E)	1.9	3.9	4.4	3.9
	Structure 3+80 (D)	1.9	3.9	4.5	3.9
	US 4+88 (C)	1.9	3.8	4.7	3.8
	US 6+16 (B)	3.2	5.2	5.7	5.3
	US 6+98 (A)	2.4	4.4	4.8	4.4
Average velocity (ft/s)	DS 1+00 (G)	2.1	3.9	4.1	3.9
	DS 2+70 (F)	1.4	2.8	2.8	2.8
	DS 3+13 (E)	1.9	3.5	4.4	3.6
	Structure 3+80 (D)	1.8	3.9	4.8	3.9
	US 4+88 (C)	1.9	3.6	3.7	3.7
	US 6+16 (B)	1.2	2.0	2.0	2.0
	US 6+98 (A)	1.7	2.4	2.2	2.3
Average shear (lb/SF)	DS 1+00 (G)	0.2	0.4	0.4	0.4
	DS 2+70 (F)	0.3	1.0	0.9	1.0
	DS 3+13 (E)	0.7	1.6	2.3	1.6
	Structure 3+80 (D)	0.2	0.5	0.7	0.5
	US 4+88 (C)	0.8	1.7	1.6	1.7
	US 6+16 (B)	0.1	0.1	0.1	0.1
	US 6+98 (A)	0.2	0.2	0.1	0.2

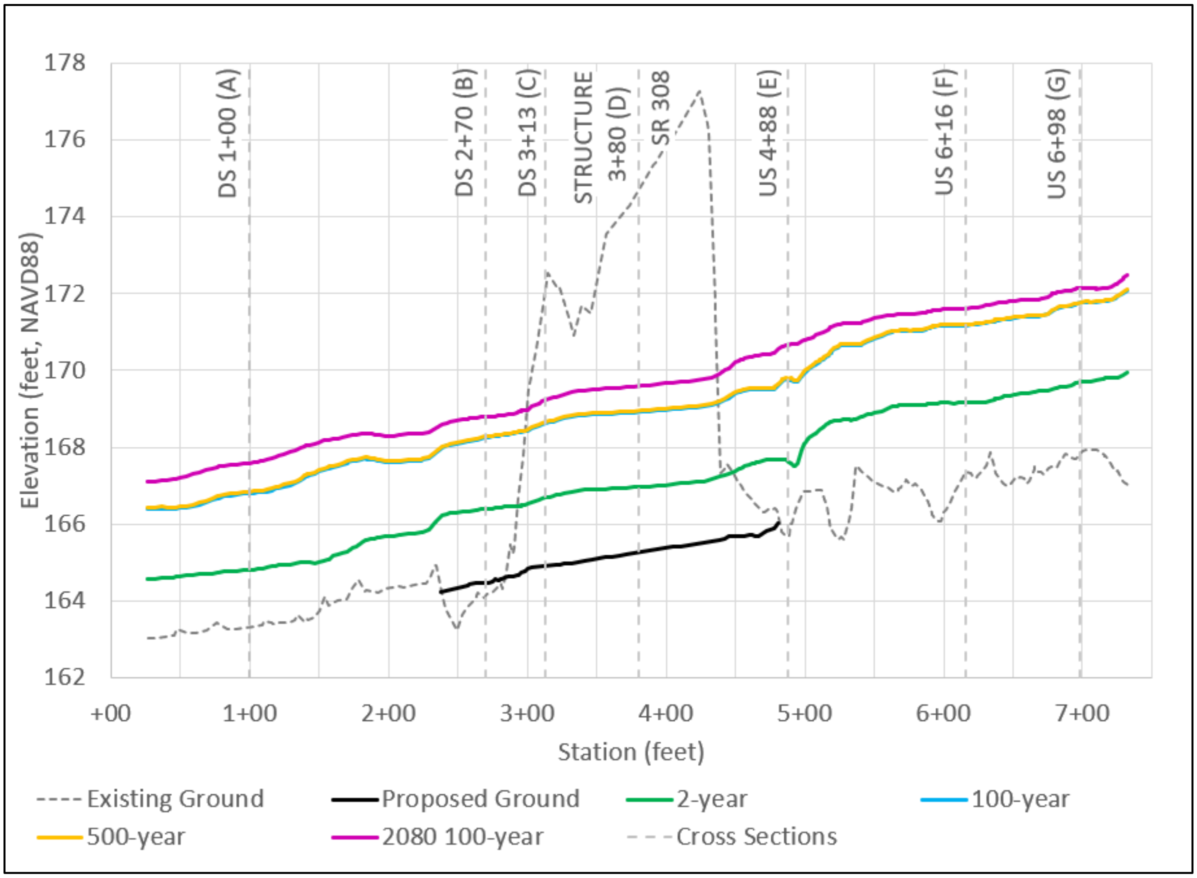


Figure 75: Proposed-conditions water surface profiles

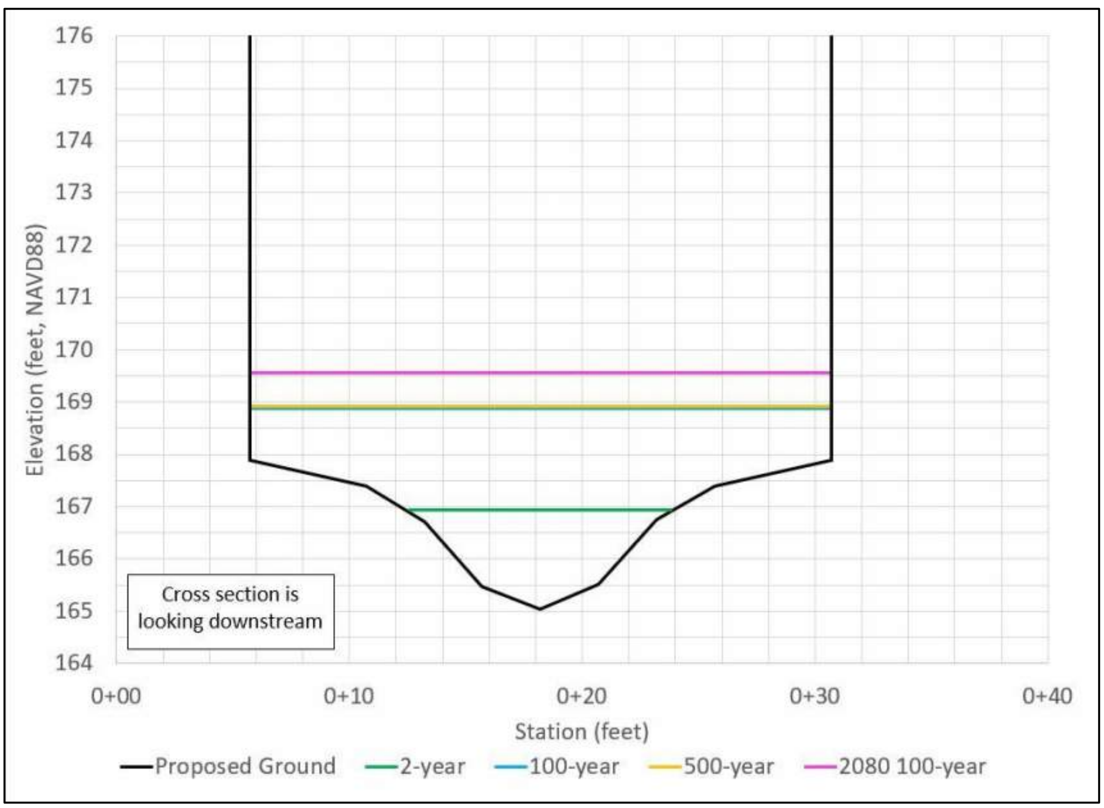


Figure 76: Typical section through proposed structure (STA 3+80)

Figure 77 shows a spatial layout of the 100-year velocities which illustrates that velocities are higher within the channel and lower in the overbank areas. The 100-year velocity along the stream centerline ranges from 2.0 feet per second to 3.9 feet per second (see Table 16), whereas the overbank area velocities range from 0.5 feet per second to 3.1 feet per second. Hydraulic analysis of the 2080 100-year flow shows that velocities in the channel and overbank areas could increase by as much as 1.2 feet per second.

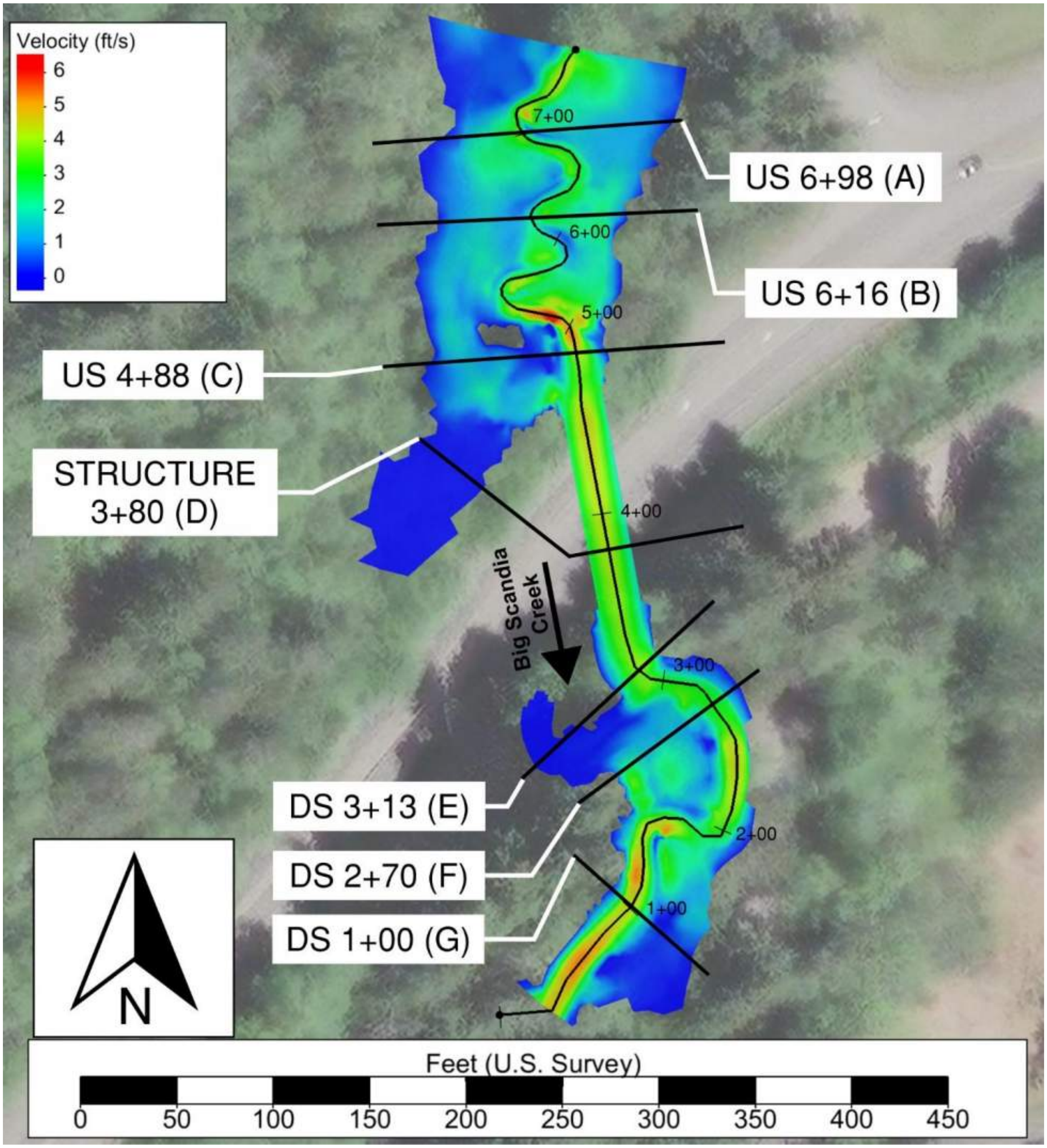


Figure 77: Proposed-conditions 100-year velocity map

Table 16: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 1+00 (G)	0.5	3.9	1.2	0.9	4.1	2.0
DS 2+70 (F)	1.0	2.8	1.6	0.8	2.8	2.7
DS 3+13 (E)	3.1	3.5	0.5	3.5	4.4	0.6
Structure 3+80 (D)	2.7	3.9	0.3	3.9	4.8	0.5
US 4+88 (C)	1.4	3.6	0.7	1.4	3.7	1.6
US 6+16 (B)	2.1	2.0	1.1	2.7	2.0	1.4
US 6+98 (A)	1.2	2.4	1.5	1.7	2.2	1.5

[a]Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.

6 Floodplain Evaluation

This project is within a FEMA special flood hazard area (SFHA) Zone A; see Appendix A for FIRM. The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

Changes in water surface elevations from existing conditions to proposed conditions for the 100-year event are limited to the immediate vicinity of the crossing. The proposed project eliminates the backwater condition that is present during existing conditions (see Section 5.2). This change means that the water surface elevation immediately upstream of the culvert decreases due to the proposed crossing (see Section 5.4). Correspondingly, the WSE immediately downstream of the culvert increases slightly as velocities through the crossing return to typical open channel levels. Figure 78 shows the expected change in the water surface profiles from existing conditions to proposed conditions. The existing and proposed 100-year water surface profiles intersect at station 2+30 and again at 2+75. Figure 79 shows the increases and decreases in flood elevations along with floodplain areas that will change from dry to wet (wetted) or wet to dry (dried). Because there are no properties or infrastructure near the crossing that may be impacted by the 100-year event, there are no flood risks to properties or infrastructure.

A flood risk assessment will be developed during later stages of the design.

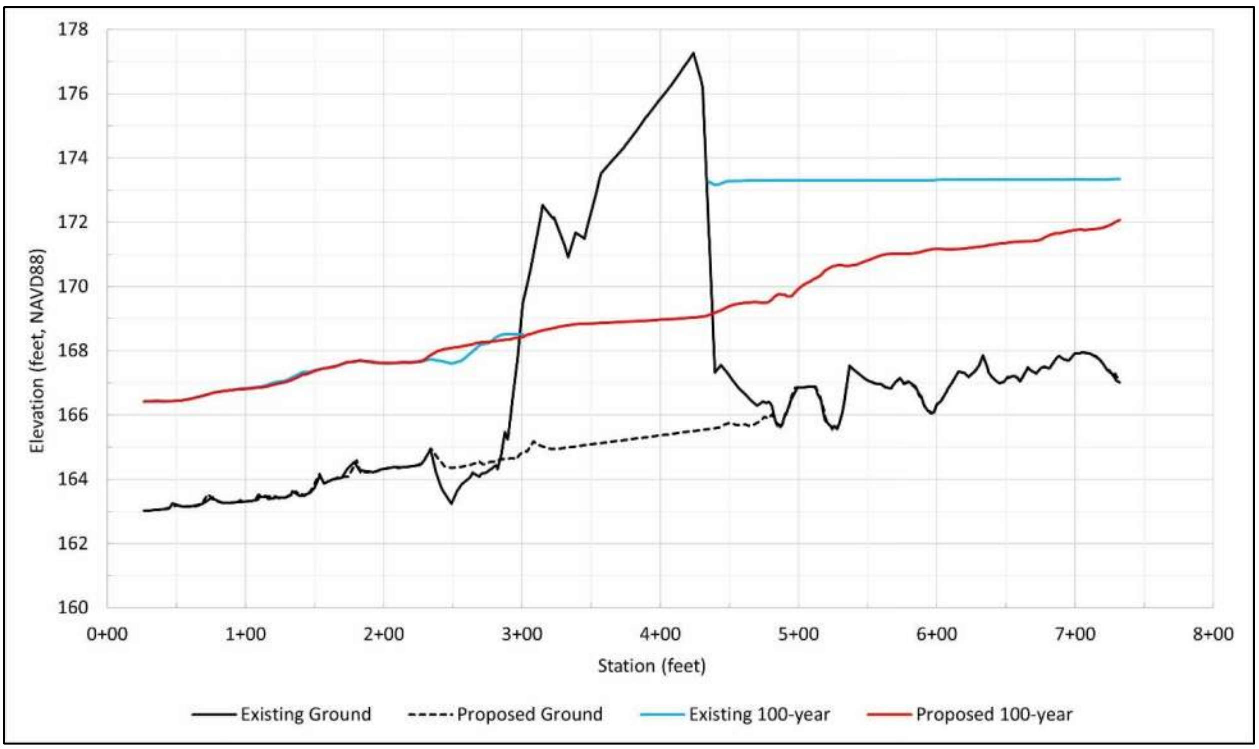


Figure 78: Comparison of existing and proposed-conditions 100-year water surface profiles

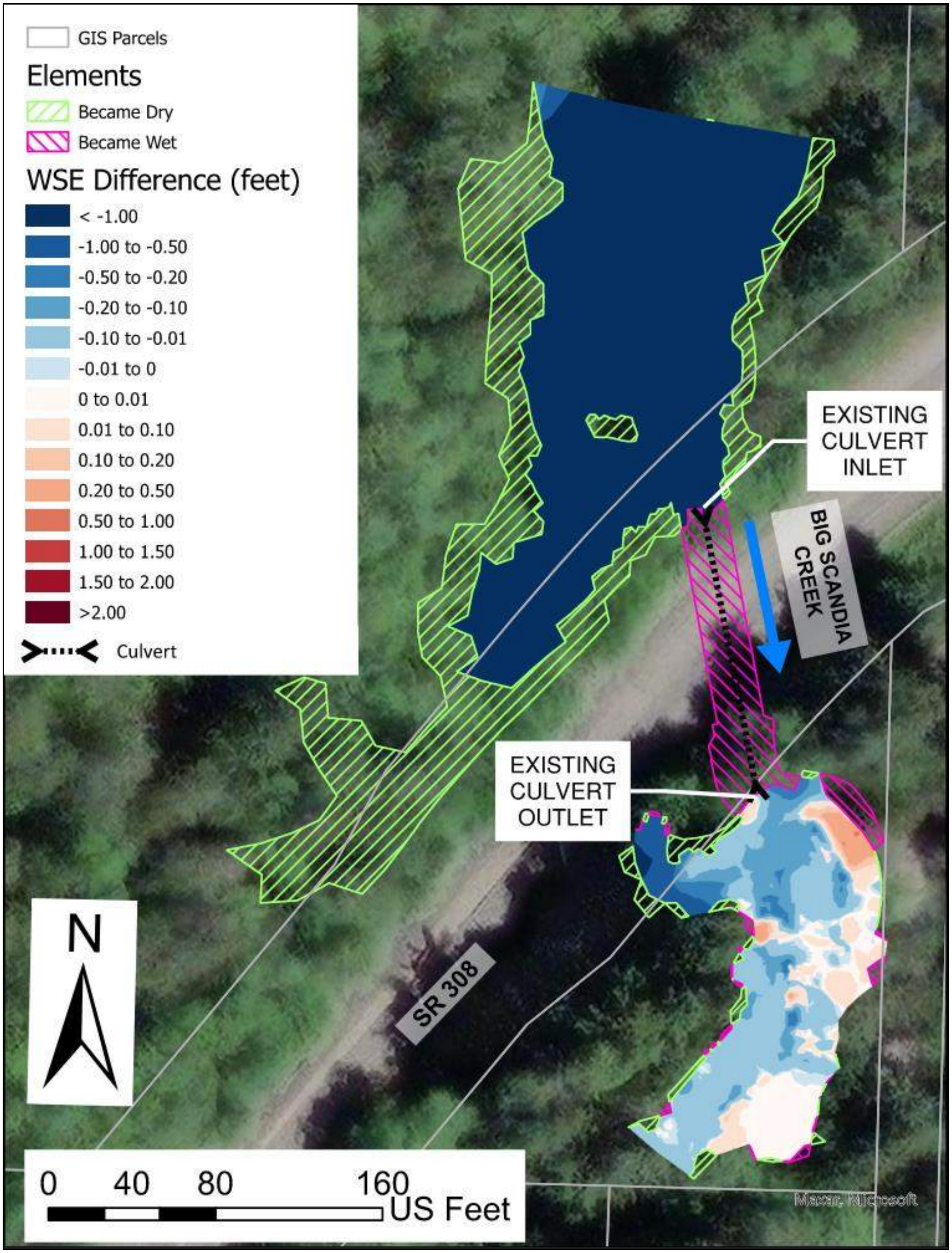


Figure 79: 100-year WSE change from existing to proposed conditions

7 Preliminary Scour Analysis

This section is not ready for review at this time and will be provided with a future submittal.

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation, and evaluation of preliminary total scour are based on available data, including but not limited to hydraulic modeling results, the geotechnical scoping memo, and LiDAR data of the channel longitudinal slopes. This evaluation is considered preliminary and is not to be taken as a final recommendation.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended minimum hydraulic opening (25 feet), and considering the potential for lateral channel migration, preliminary scour calculations for the scour design flood and scour check flood, both of which are the 2080 projected 100-year event (206 cfs), were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012).

Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections. Other flow events, including the 2-year (28 cfs), 10-year (71 cfs), 25-year (104 cfs), 50-year (131 cfs), 100-year (180 cfs), and 500-year (185 cfs) were evaluated but were not found to produce the largest scour depths. Therefore, reporting on those events was not conducted. It was assumed without contacting WSDOT HQ Hydraulics, that the design of the proposed structure should account for the potential scour at the projected 2080 100-year flow event. A more refined analysis will be completed during final hydraulic design.

7.1 Lateral Migration

The geotechnical scoping memo for the site included two soil borings (see Section 2.3). The soil borings showed glacial deposits with fine-grained 'soft to medium stiff silt with sand' and 'medium dense sand'. The soil borings confirmed the geologic and soil mapping data presented in Section 2.3. The geotechnical scoping memo determined that the soils are cohesionless and have high (II) HEC-18 erodibility. Therefore, there is risk of lateral migration of Big Scandia Creek at this crossing. Controlling features like mature trees upstream of the project site and existing infrastructure like Cox Avenue downstream of the crossing will restrict large scale lateral migration (see Section 2.7.5), but the dynamic physical processes resulting from natural and constructed channel forcing elements, such as boulder clusters, will encourage small scale lateral migration. Due to the unconfined nature of the stream (see Section 2.7.2.1), a meander belt width assessment was conducted (see Section 4.1.1) which revealed a typical meander belt width of 25 feet.

The expected lateral migration during the life of the proposed crossing will be contained within the proposed structure because the structure width accounts for the meander belt width upstream and downstream of the crossing (see Section 4.2.2). The watershed upstream of the crossing appears to have ample sediment supply due to the lack of both recent erosion and downcutting in the project area (see Section 2.7.4), as well as geologic mapping showing an upstream Quaternary mass wasting deposit which is synonymous with landslides that create sediment supplies for streams. The geotechnical scoping memo also listed the presence of two unstable slopes along SR 308 within 1.2 miles of the crossing.

7.2 Long-term Degradation of the Channel Bed

The proposed channel slope closely mimics the existing conditions, but a potential long-term degradation of about 2 feet is expected to occur at this site. The geomorphic equilibrium profile was estimated using LiDAR data and grade control points, such as the downstream crossing at Cox Avenue NW and the upstream private road crossing (see Figure 80). Section 2.7.4 discusses the vertical channel stability. Long-term degradation will be further quantified in the Final Hydraulic Design Report. Long-term degradation results are presented in Table 17. Base-level controls such as bedrock, non-erodible material, or nick points were not identified in the field nor in any supporting documentation, such as the geotechnical scoping memo.

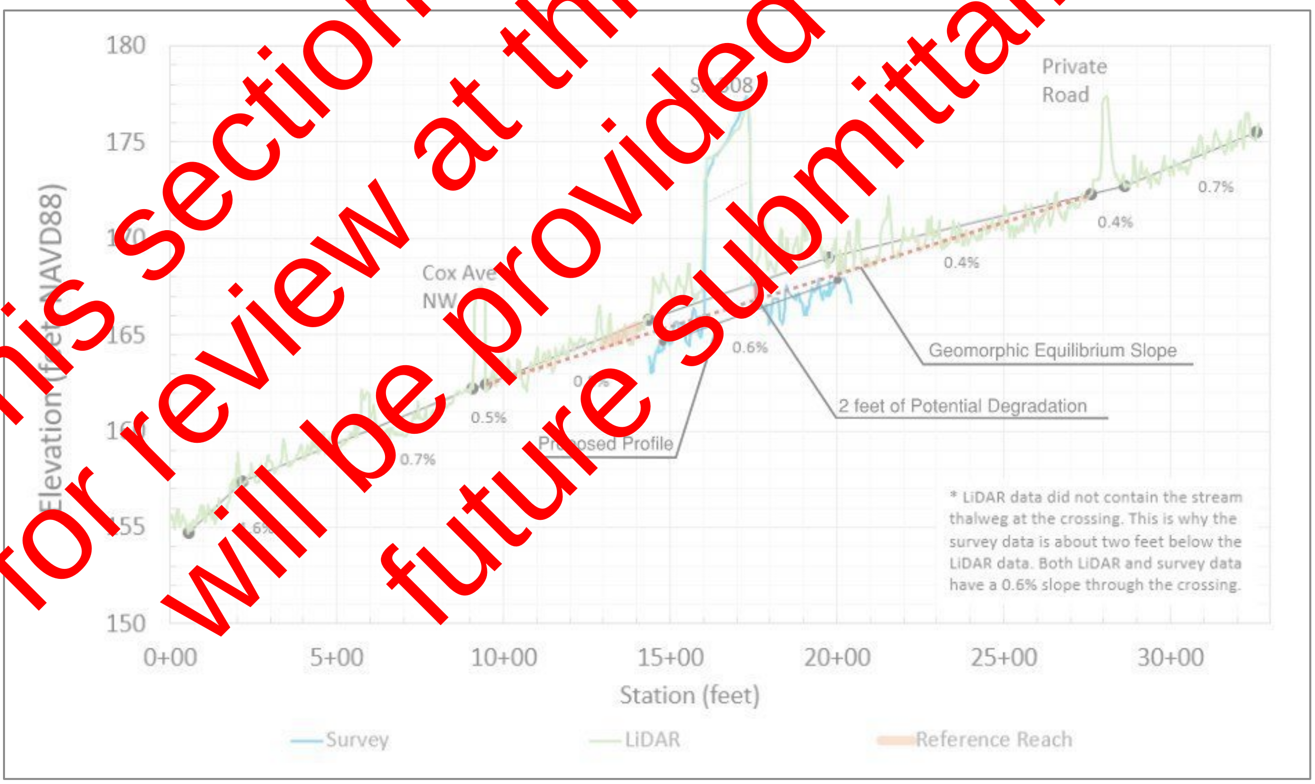


Figure 80: Potential long-term degradation at the proposed structure upstream face

7.3 Contraction Scour

The 2-year, 10-year, 25-year, 50-year, 100-year, 500-year, and 2080 100-year events were evaluated for contraction scour. The critical velocity index (CVI) was calculated for each recurrence interval with the proposed median sediment size (D_{50}) of 1 inch (see Section 4.3.1). The CVI shows that sediment will not mobilize resulting in clear bed scour conditions within the main channel. See Appendix K for critical velocity figures and output of the Federal Highway

Administration's Hydraulic Toolbox Version 5.1.4 (FHWA 2021) scour output figures. The proposed sediment size was selected for scour analysis due to the prevailing clear water scour condition, and the location of the approach section being located within the proposed grading.

Both clear water and live bed contraction scour conditions were calculated using the FHWA Hydraulic Toolbox computer program for the proposed minimum hydraulic opening of 25 feet. Both scour conditions were calculated as a conservative measure so the maximum scour can be evaluated, even though the CVI shows prevailing clear water conditions. For the scour design and check floods, the contraction scour is 0.0 feet for clear water and 0.0 feet for live bed conditions.

7.4 Local Scour

A preliminary analysis of local scour was performed using the FHWA Hydraulic Toolbox computer program, Version 5.1.4 (FHWA 2021). Local scour includes scour at bridge abutments, piers, and bends.

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design flood and scour check flood. The 2-year, 10-year, 25-year, 50-year, 100-year, 500-year, and 2080 100-year events were evaluated for abutment scour. The hydraulic influence of the modeled vertical culvert walls is effectively the same as the hydraulic influence of vertical bridge abutments. Because main channel lateral migration is likely to occur within the proposed structure, abutment scour was evaluated relative to the thalweg depth and not necessarily the depth of flow at the abutment during the modeled flow scenarios.

Abutment scour calculations estimate a depth of scour of 0.4 feet for the scour design and check floods. See Appendix K for the Hydraulic Toolbox calculation outputs, SMS Bridge Scour coverage figures showing the locations of the abutments and channel banks, as well as the CVI and velocity vector coverages.

7.4.3 Bend Scour

Bend scour was not quantified at this crossing given the lack of anticipated bends in the vicinity of the crossing.

7.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood at the proposed Big Scandia Creek crossing of SR 308 as shown in the plans dated November 14, 2022, are provided in Table 17. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 17.

Table 17: Scour analysis summary

Calculated Scour Components and Total Scour for SR 308 Big Scandia Creek		
	Scour design flood (2080 100-year)	**Scour check flood (2080 100-year)**
Long-term degradation (ft) [a]	2.0	2.0
Contraction scour (ft) [a]	0.0	0.0
Abutment scour (ft) [a]	0.4	0.4
Total depth of scour (ft) [a]	2.4	2.4

[a]Scour depths are reported relative to the thalweg elevation.

This section is not ready for review at this time and will be provided with a future submittal.

8 Scour Countermeasures

Scour countermeasures are not anticipated to be required for this crossing. Instead, it is recommended that bottom of walls and embankments be placed 2 feet below the total scour depth, given 2.4 feet of total scour (see Section 7.4.2) is predicted. Streambed sediment will also be placed at a minimum thickness of 3 feet within the proposed structure (see Section 4.3.1). If scour countermeasures are needed, they may not encroach within the minimum hydraulic opening. If LWM is placed within the structure at future design phases, scour countermeasures will be needed to protect against scour near the LWM pieces. Based on the information we have right now, there are no properties or right of way issues for potential countermeasure construction. These decisions are based on preliminary scour calculations and will need to be reevaluated during final design.

9 Summary

Table 18 presents a summary of the results of this PHD Report.

Table 18: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	18,202 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	12.0 ft	2.7.2 Channel Geometry
	Concurrence BFW	12.5 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	88.8 ft	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	7.1	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	180 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	296 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	Yes	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	No	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	1.0%	2.6.2 Existing Conditions
	Reference reach	0.6%	2.7.1 Reference Reach Selection
	Proposed	0.6%	4.1.3 Channel Gradient
Hydraulic width	Existing	6 ft	2.6.2 Existing Conditions
	Proposed	25 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	3.0 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	140 ft	2.6.2 Existing Conditions
	Proposed	127 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type	N/A	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	0	4.3.2 Channel Complexity
	Boulder clusters	3 - 4	4.3.2 Channel Complexity
	Coarse bands	0	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Mobile wood	No	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	Yes	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	Yes	6 Floodplain Evaluation
Scour	Analysis	See link	7 Preliminary Scour Analysis
	Scour countermeasures	Yes	8 Scour Countermeasures
Channel degradation	Potential?	0 - 2 feet	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-term Degradation of the Channel Bed

This section is not ready for review at this time and will be provided with a future submittal.

References

Aquaveo. 2021. SMS Version 13.1.15.

Arneson, L.A., L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper. 2012. Evaluating Scour at Bridges—Fifth Edition. Federal Highway Administration. Fort Collins, Colorado. Publication FHWA-HIF-12-003 (HEC No. 18).

Barnard, R.J., J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife. Olympia, Washington.

Castro, Janine M., and Aaron Beavers. 2016. *Providing Aquatic Organism Passage in Vertically Unstable Streams*. Water 8, no. 4: 133. https://doi.org/10.3390/w8040133.

Chow, V.T. 1959. Open Channel Hydraulics, McGraw-Hill Book Company, New York.

Dewitz, J. (2021). National Land Cover Database (NLCD) 2019 Products [Data set]. U.S. Geological Survey. https://doi.org/10.5066/P9KZCM54

DNR Geology Portal. 2022. Washington State Department of Natural Resources Geologic Information Portal: https://geologyportal.dnr.wa.gov/2d-view#wigm?-13667520,-13649176,6055258,6065358?Surface_Geology,24k_Surface_Geology,Geologic_Units_24K. Accessed on April 8, 2022.

Fox, Martin and Bolton, Susan. 2007. *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forests Basins of Washington Stat. North American Journal of Fisheries Management.* Vol. 27, Issue 1. Pg. 342–359.

FPDSI, 2021. Fish Passage and Diversion Screening Inventory Database. http://apps.wdfw.wa.gov/fishpassagephotos/Reports/996804_Report.pdf Accessed on Dec 4, 2021

SWIFD, 2021. Statewide Washington Integrated Fish Distribution Database. Statewide Washington Integrated Fish Distribution | Statewide Washington Integrated Fish Distribution | Washington State Geospatial Open Data Portal. Accessed Dec 4, 2021

Lagasse, P.F., P.E. Clopper, J.E. Pagan-Ortiz, L.W. Zevenbergen, L.A. Arneson, J.D. Schall, L.G. Girard. 2009. *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance—Third Edition*. Federal Highway Administration. Fort Collins, Colorado. Publication FHWA-NHI-09-111.

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E. 2016. Magnitude, frequency, and trends of floods at gaged and ungauged sites in Washington, based on data through water year 2014 (ver. 1.2, November 2017): U.S. Geological Survey Scientific Investigations Report 2016-5118, 70 p., http://dx.doi.org/10.3133/sir20165118.

Porter, S.C., and Swanson, T.W. 1998. Radiocarbon age constraints on rates of advance and retreat of the Puget Lobe of the Cordilleran Ice Sheet during the last glaciation: Quaternary Research, v. 50, pp. 205-213.

PRISM Climate Group, 2021. Oregon State University, https://prism.oregonstate.edu, accessed 05 Dec 2021.

United States Army Corps of Engineers. 2010. HEC-RAS River Analysis System V.5.0.7.

USBR (United States Department of the Interior, Bureau of Reclamation). 1984. "Computing Degradation and Local Scour, Technical Guideline for Bureau of Reclamation." Denver, Colorado.

USBR. 2017. SRH-2D Version 3.2.4.

USDA (United States Department of Agriculture). 2001. *Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring.*

USDA. 2008. *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings, Appendix E.*

USGS (United States Geological Survey). 2016. The StreamStats program, online at http://streamstats.usgs.gov, accessed on December 20, 2021.

WDFW (Washington Department of Fish and Wildlife). 2019. *Fish Passage and Surface Water Diversion Screening Assessment and Prioritization Manual.* Olympia, Washington.

WDFW. 2020. Washington State Fish Passage. Website accessed online: https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html

WDFW. 2021. Habitat Assessment Data for Big Scandia Creek (culvert 990235) at SR 308 MP 0.94. Unpublished.

Washington Department of Fisheries. 1975. A Catalog of Washington Streams and Salmon Utilization. 4 Volumes. Olympia, Washington.

WSDOT (Washington State Department of Transportation). 2022a. *Draft Hydraulics Manual*. Olympia, Washington. Publication M 23-03.06.

WSDOT. 2022b. *Standard Specifications for Road, Bridge, and Municipal Construction*. Olympia, Washington. Publication M 41-10.

Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning’s Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

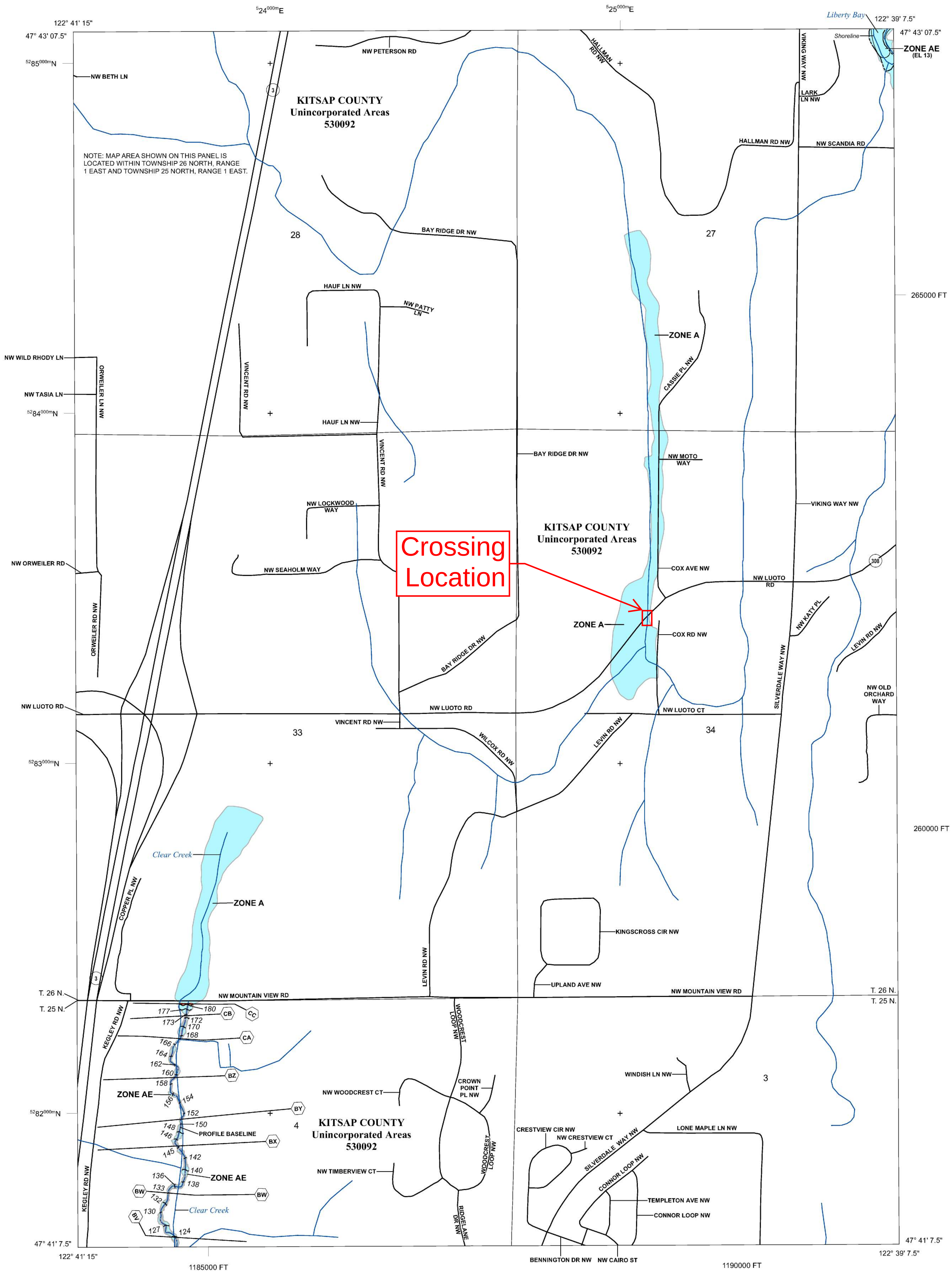
Appendix J: Reach Assessment

Appendix K: Scour Calculations

Appendix L: Floodplain Analysis (FHD ONLY)

Appendix M: Scour Countermeasures Calculations (FHD ONLY)

Appendix A: FEMA Floodplain Map



FLOOD HAZARD INFORMATION

SEE FIS REPORT FOR ZONE DESCRIPTIONS AND INDEX MAP

THE INFORMATION DEPICTED ON THIS MAP AND SUPPORTING DOCUMENTATION ARE ALSO AVAILABLE IN DIGITAL FORMAT AT

HTTP://MSC.FEMA.GOV

SPECIAL FLOOD HAZARD AREAS	Without Base Flood Elevation (BFE) *Zone A, V, A99*
	With BFE or Depth *Zone AE, AO, AH, VE, AR*
	Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD	0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
	Future Conditions 1% Annual Chance Flood Hazard *Zone X*
	Area with Reduced Flood Risk due to Levee See Notes. *Zone X*
OTHER AREAS	NO SCREEN Areas Determined to be Outside the 0.2% Annual Chance Floodplain *Zone X*
	Area of Undetermined Flood Hazard *Zone D*
GENERAL STRUCTURES	Channel, Culvert, or Storm Sewer
	Accredited or Provisionally Accredited Levee, Dike, or Floodwall
	Non-accredited Levee, Dike, or Floodwall
	E 18.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation (BFE)
	8 Coastal Transect
	Coastal Transect Baseline
	Profile Baseline
	Hydrographic Feature
	513 Base Flood Elevation Line (BFE)
OTHER FEATURES	Limit of Study
	Jurisdiction Boundary

NOTES TO USERS

For information and questions about this map, available products associated with this FIRM including historic versions of this FIRM, how to order products or the National Flood Insurance Program in general, please call the FEMA Map Information eXchange at 1-877-FEMA-MAP (1-877-336-2627) or visit the FEMA Map Service Center website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the website. Users may determine the current map date for each FIRM panel by visiting the FEMA Map Service Center website or by calling the FEMA Map Information eXchange.

Communities annexing land on adjacent FIRM panels must obtain a current copy of the adjacent panel as well as the current FIRM Index. These may be ordered directly from the Map Service Center at the number listed above.

For community and countywide map dates refer to the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in the community, contact your Insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

Base map information shown on this FIRM was provided in digital format by Washington State GIS, Kitsap County GIS and Kitsap County Auditor and Elections.

SCALE

N

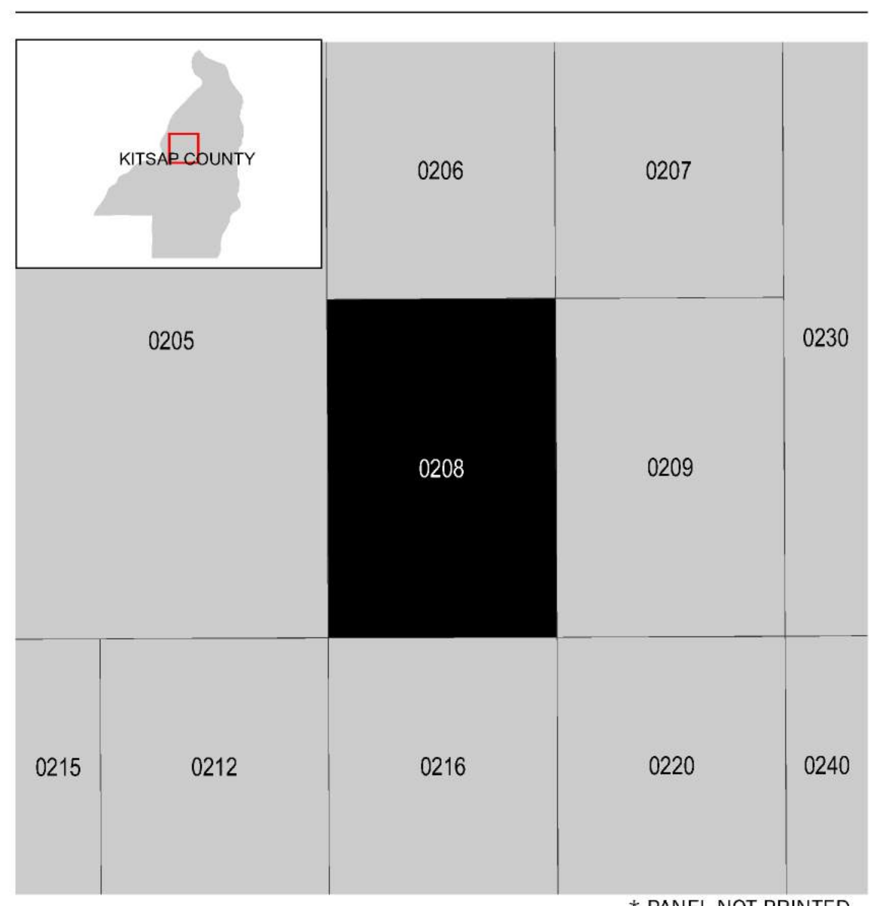
Map Projection:
NAD 1983 UTM Zone 10N;
Western Hemisphere; Vertical Datum: NAVD 88

1 inch = 500 feet 1:6,000

0 500 1,000 2,000 Feet

0 125 250 500 Meters

PANEL LOCATOR



* PANEL NOT PRINTED

FEMA

National Flood Insurance Program

NATIONAL FLOOD INSURANCE PROGRAM
FLOOD INSURANCE RATE MAP

KITSAP COUNTY, WASHINGTON
AND INCORPORATED AREAS

PANEL **208** OF **525**

FEMA

Panel Contains:

COMMUNITY	NUMBER	PANEL	SUFFIX
KITSAP COUNTY	530092	0208	F

VERSION NUMBER
2.2.2.1

MAP NUMBER
53035C0208F

MAP REVISED
FEBRUARY 3, 2017

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: Y-12554 - Task Order AC
	Project Name: Olympic Region GEC	Date: 12/01/2021
	Project Office: WSDOT HQ Hydraulics Office - Olympic Region	Time of Arrival: 12:30 pm
	Stream Name: Big Scandia Creek	Time of Departure: 13:30 pm
WDFW ID Number: 990235	Tributary to: Liberty Bay	Weather: Partly Sunny, 55° F
State Route/MP: SR 308 MP 0.94	Township/Range/Section/ ¼ Section: Township 26 North, Range 01 East, Section 34	Prepared By: Dan Christensen & Josh Owens
County: Kitsap	Purpose of Site Visit: Site Visit 2- Stream Assessment, Project Constraints	WRIA: 15.0280

Meeting Location:
Northwest corner of intersection of NW Luoto Rd (SR 308) and Cox Ave NW

Attendance List:

Name	Organization	Role
Micco Emeson	David Evans and Associates, Inc.	Junior Engineer
Josh Owens	David Evans and Associates, Inc.	Geomorphologist
Sulochan Dhungel	David Evans and Associates, Inc.	Senior Engineer
Gray Rand	David Evans and Associates, Inc.	Senior Biologist
Bryan Darby	David Evans and Associates, Inc.	Biologist

Bankfull Width:

Upstream of the culvert the channel has steep banks and is highly meandered. Six bankfull widths were measured at the project site. Four bankfull width measurements were taken on the upstream side of the culvert, two at straight channel sections that were 10 feet and 12 feet, and two at the widest point in meander bends that were 12 feet and 14 feet. Two bankfull width measurement were taken on the downstream side of the culvert in the reference reach. Both bankfull widths in the reference reach were 10 feet and 15 feet. The 15-foot wide BFW measurement seemed to be larger than the representative channel width based on the other BFW measurements. DEA recommends the BFW for the reach should be 12 feet wide.

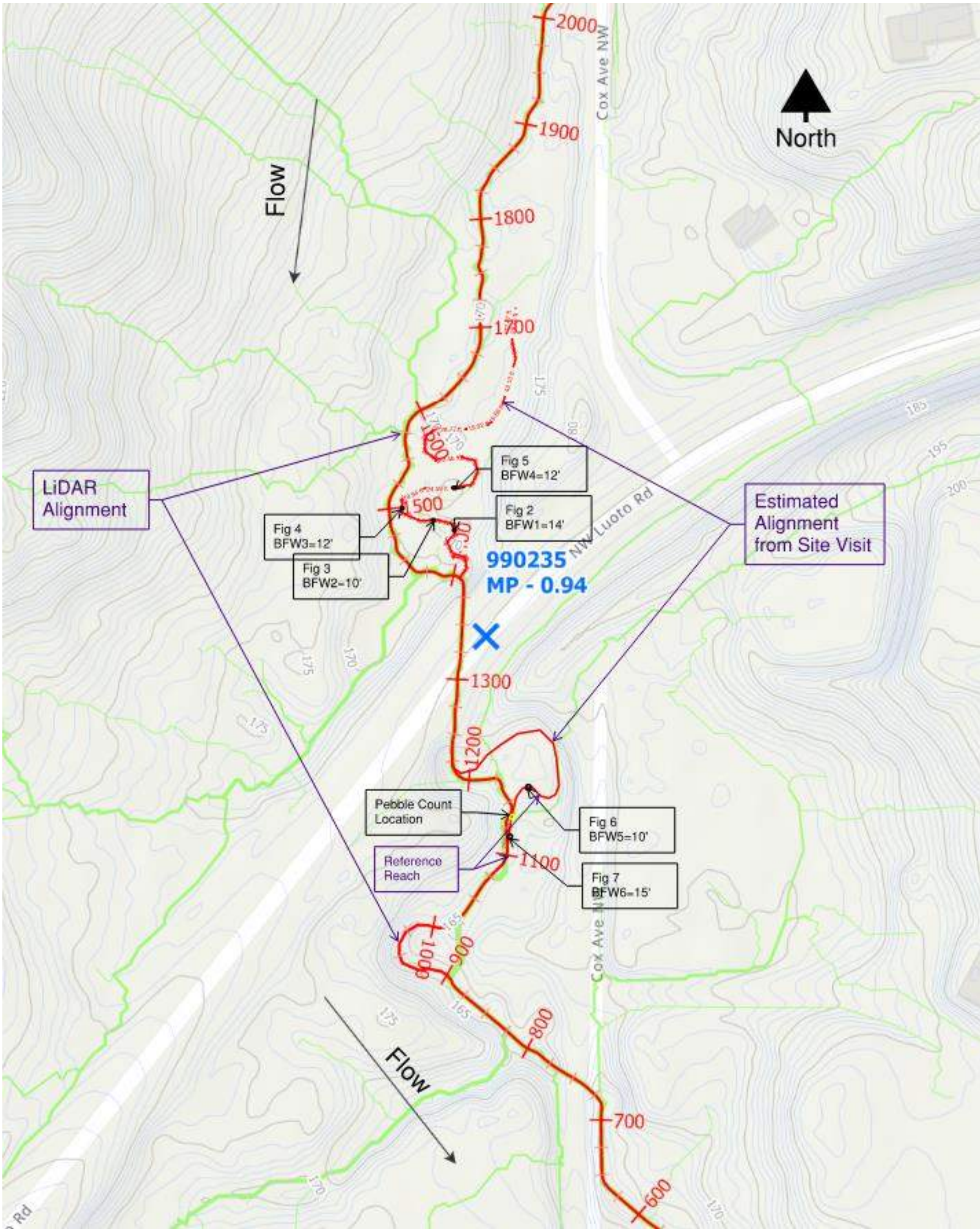


Figure 1. Bankfull Width Measurement Locations


Figure 2. Approximately 50 feet upstream of culvert, Bankfull width = 14 feet


Figure 3. Approximately 65 feet upstream of culvert, Bankfull width = 10 feet


Figure 4: Approximately 100 feet upstream of culvert, Bankfull width = 12 feet


Figure 5: Approximately 180 feet upstream of culvert, Bankfull width = 12 feet.


Figure 6: Approximately 180 feet downstream of culvert, Bankfull width = 10 feet.


Figure 7: Approximately 245 feet downstream of culvert, Bankfull width = 15 feet.

Reference Reach:

The reference reach is a 80-foot segment of stream that begins approximately 180 feet downstream of the culvert outlet (Figure 6), extending to a distance approximately 260 feet downstream of the culvert outlet (Figure 7). This section was chosen because it is downstream from the influence of the culvert and what appears to be a straightened and steepened section of stream where runs adjacent to the toe of the roadway embankment Cox Ave NW. The reference reach has overbanks accessible to flooding with a combination of pools (1.5 feet depth) to shallow sections resulting from in-channel aggradation of sandy and gravelly material. The reference reach is within mature trees without a dense understory.

The channel upstream of the culvert for approximately 250 feet is in a low-relief area with a high degree of sinuosity because the channel makes multiple 180-degree bends (Figure 8). At the time of the site visit, the upstream reach had deeper pool sections, up to 2.5 feet deep with steep banks approximately 2 feet above water level.. The bed consisted of fine sand within the meander section with no observable pebbles or gravels. This meandering section of stream appears to be local to the upstream section and not representative of the overall system. Upstream of the meander section, the channel runs adjacent to Cox Ave NW and was likely impacted by the roadway construction.

Figure 8: 180-degree meander bend upstream of culvert.

Data Collection:

Data was collected by staff engineers from David Evans and Associates, Inc. on December 1, 2021.

The upstream end of the site was visited first. Observations were recorded, including bankfull width measurements. A pebble count was not conducted upstream because the deep meandering section is dominated with fines with no observable larger pebbles or gravels.

The downstream side of the culvert was visited next, and a reference reach was selected downstream of the culvert. Two bankfull width measurements and a pebble count were collected within the reference reach.
Flow in the channel during these site visits was on the order of 1 cubic foot per second or less. See figure 9.


Figure 9. Flow entering the upstream side of the culvert.

Observations:

The site visit occurred during winter baseflow conditions with no evidence of recent erosion or aggradation occurring. The culvert inlet was clear of debris and blockage. There appeared to be a minor scour pool at the culvert outlet and a grade control consisting of a combination of large rocks and wood material about 10 feet downstream of the culvert resulting in shallow flow and a drop of about 3 to 4 inches (Figure 10).


Figure 10: Minor scour pool with grade control consisting of large rock and wood material at the downstream end.

Approximately 25 feet downstream of the culvert a small surface channel that drains the road enters the stream and has caused some localized bank erosion and has exposed larger gravels, indicating that larger gravels are present in the system and may be mobilized as bed load during high flows. For most of the reach, the surface of the streambed is composed of sands and fines that likely cover coarser materials during the receding limb of runoff events. Large gravel material was also visible downstream of the culvert where the channel is adjacent to the roadway. This short section of channel is steeper with audible flow indicating that the channel was likely straightened and steeped during construction of Cox Ave NW. No other erosion of incision was observed at this location. There are mature trees at the downstream end of the culvert with some undercut roots and some trees leaning towards the channel.

Upstream of the culvert the channel was highly sinuous for approximately 250 feet as it flowed through a low relief area. This appeared to be a localized characteristic of this channel that was not typical of the overall channel form. The channel appeared incised with steep banks. Although, there was no evidence of recent erosion or scour and the bed consisted of sand and fine sediment. There was some undercut roots observable and trees were generally smaller than upstream (up to 18 inches DBH estimate) with more understory vegetation.

The established trees along the channel and no evidence of recent incision or widening indicates that the channel form and profile are stable. There was infrequent woody material within the channel except for a few deeper pool and refuge areas that were created by the undercutting of tree roots. Wood material does not appear to be a major influence on the geomorphology of this reach. The lack of wood in the stream may reduce the habitat function.

Pebble Counts:

One Wolman Pebble Counts (PC) was conducted at this site within the reference reach. Pebble counts were not conducted upstream of the culvert because within the sinuous reach it was observed that the bed material consisted entirely of sands less than 2 mm. (Figure 11). The pebble count location can be seen in Figure 12. The pebble count was conducted along an approximately 50-foot section of the reference reach where the flow was shallower, and the sandy bed material was interspersed with gravels (see Figures 12 and 13).

Figure 11: Sandy bed material within the sinuous portion of the channel upstream of the culvert.

Figure 12. Typical sediment in pebble count location with Gravelometer


Figure 13. Typical sediment in pebble count location in hand

Photos:
See above.

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☐ If no, then stop here.* *Yes ☒ If yes, then fill out the proceeding section for each sample.*

Sample #:	Work Start:	Work End:	Latitude:	Longitude:
PC-1	Dec. 1, 2021 12:30	Dec. 1, 2021 13:30	47.70001	-122.64682

Summary/description of location:

One Wolman Pebble Counts (PC) were taken at this location. One PC was conducted approximately 200-250 feet downstream of the culvert outlet.

Description of work below the OHWL:

Work within the OHW included Wolman Pebble Counts which consists of walking along the streambed to collect 100 random samples of sediment. These samples are then measured in-situ to determine the gradation of the existing streambed sediment. After being measured the samples are returned to the stream.

Description of problems encountered:

No Problems occurred during the pebble count or site visit.

Concurrence Meeting

Concurrence Meeting	Date: 12/17/2021	Time of Arrival: About 11 am
Prepared By: Chad Booth	Weather: N/A	Time of Departure: About 1 pm

Attendance List:

Name	Organization	Role
Cade Roler	WSDOT	
Nazmul Alam	WSDOT	
Alison O'Sullivan	Suquamish Tribe	
David Collins	WDFW	
Amber Martens	WDFW	
Damon Romero	WSDOT	
Heather Pittman	WSDOT	
Steve Seville	DEA	
Micco Emeson	DEA	
Nich VanBuecken	DEA	
Michelle Kinsey	Jacobs	
Nam Siu	WDFW	
Alexia Henderson	WDFW	
Dan Christensen	DEA	

Bankfull Width:

Upstream BFW measurements of 11.5 to 12.0 ft were measured in 3 locations. The channel may be artificially altered which provided a consistent BFW and an unnatural rate of meander. Downstream BFW's varied from 10 to 10.5 feet and as wide as 15 feet at the tailout where the pebble count was completed. An average BFW of 12 feet was concurred upon by DEA, WSDOT, and co-managers.

Reference Reach:

Reference reach location concurred upon between DEA, WSDOT, and co-managers.

Observations:

Topographic survey was not completed at the time of site visit 2 or 3. WSDOT and consultant team is unsure if the stream is confined or unconfined. This is important to know as the confinement will drive the size of and process for determining the minimum hydraulic opening. DEA estimated a FUR of about 3 based on LiDAR and field observations. A FUR of 3 is the break point between confined and unconfined streams. A final FUR will be determined with survey information when available. Grading and construction activities should avoid impacts to the upstream riparian area as much as possible. Streambed material consists of all fines with very little gravels or cobbles upstream of crossing.

Discussed to possibly realign thalweg which may cause an approximate 105 linear feet of channel loss and would shorten the overall crossing. Also discussed the potential to leave existing channel in place and provide off channel habitat in conjunction with the realignment. Small gravels and cobbles were present in the large pool below culvert outlet about 50 feet downstream. WDFW suggested burying wood and slash in streambed as well as inside the culvert.

Photos:

No relevant photos.

Fish Passage Project Site Visit - Determining Project Complexity

PROJECT NAME:	**WSDOT OLYMPIC REGION GEC**
WDFW SITE ID:	**990235**
STATE ROUTE/MILEPOST:	**SR 308**
SITE VISIT DATE:	**December 1, 2021**
ATTENDEES:	**Micco Emeson; Josh Owens; Sulochan Dhungel; Gray Rand; Brian Darby**
ANTICIPATED LEVEL OF PROJECT COMPLEXITY - Low/Medium/High (*additional considerations or red flags may trigger the need for new discussions*):	**Low to slightly Medium. Primarily low-complexity. There may be some minor channel regrade just downstream of the outlet to smooth out the slight drop (approximately 4 inches) at the end of the scour hole and debris dam. The site could be medium complexity if a new culvert alignment is chosen to straighten the skew of the culvert to align with the general stream direction.**
IN WATER WORK WINDOW	**To be provided by WDFW.**

The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects.

Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. If there are items that need follow-up, mark those and provide a brief description in the column labeled, “Is follow up needed on this item?” The assigned level of complexity determines the appropriate agreed upon review from WDFW (see review parameters here (*final full doc goes here*)). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Stream grading	✓			Medium length culvert ~140 feet. No channel grading expected.
Risk of degradation/aggradation	✓			Limited signs of sediment deposition u/s and d/s end. Head cut risk is low.
Channel realignment	✓			The outlet could be moved to the east to align with d/s reach.
Expected stream movement		✓		Lateral movement occurs at u/s. Many 180 ° bends and under-cut tree roots at u/s.
Gradient	✓			Stream Slope is flat. U/S 0.005 ft/ft. D/S 0.007 ft/ft
Potential for backwater impacts	✓			No expected backwater impacts except local ponding at outlet
Meeting requirements for freeboard		✓		~3.5 feet of fill depth (u/s) above existing culvert. Should be enough for proposed.
Stream size, and Bankfull Width	✓			Stream size is medium (~110 cfs; 100yr StreamStats), BFW ~ 12 feet.
Slope ratio	✓			Slightly steeper slope on d/s than u/s end, between 0.5% & 0.7%
Sediment supply	✓			No supply or transport issues expected.
Meeting stream simulation	✓			Width will require Bridge Design method, representative ref. reach found.
Channel confinement		✓		Medium Confinement. Channel lies within 80-100 foot wide floodplain.
Geotech or seismic considerations	✓			None Expected
Tidal influence	✓			No tidal influence at this site. Channel thalweg EL > 160 feet.
Alluvial fan	✓			No Alluvial fan noted in site visit.
Fill depth above barrier	✓			Sufficient. Approximately 4 - 5 feet of fill over existing structure.
Presence of other nearby barriers	✓			No significant barriers except for a small localized drop at oulet
Presence of nearby infrastructure	✓			No nearby structures noted during site visit.
Need for bank protection	✓			Protection not anticipated.
Floodplain utilization ratio		✓		Channel is moderately confined with some overbank floodplain area.

Fish Passage Project Site Visit - Determining Project Complexity

Other: **None**				

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	**Big Scandia Creek, SR 308 MP 0.94, WDFW ID 990235**
By:	**David Evans and Associates; Roxanne Wilcox, EIT**

Design Gradation

Location: Proposed Channel

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.2	0.2	0.1	0.0
in	2.5	2.0	1.0	0.1
mm	64	50	25.4	1.9

Existing Gradation

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0.0	0.0

Existing Gradation

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0.0	0.0

Existing Gradation

Location: Existing Average

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.1	0.0	0.0	0.0
in	1.3	0.6	0.1	0.0
mm	32	14	3.3	0.8

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	[mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				100.0
4.0	102		100	71	57	45	39				100.0
3.0	76.2		80	63	45	38	34				100.0
2.5	63.5	100	63	54	37	32	28				100.0
2.0	50.8	85	47	45	29	25	22				85.0
1.5	38.1	68	30	32	21	18	16				67.5
1.0	25.4	50	20	18	13	12	11				50.0
0.50	12.7	45	5	5	5	5	5				45.0
0.19	4.75	28									27.5
0.02	0.425	10									10.0
0.003	0.0750	5									5.0
% per category		100	0	0	0	0	0	0	0	0	--> 100%
% Cobble & Sediment		100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

United States Forest Service (USFS)

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

Appendix E - Methods for Streambed Mobility/Stability Analysis

Range of Suitability:

$D_{84\ ranging}$ between 0.40 in and 10 in

Uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

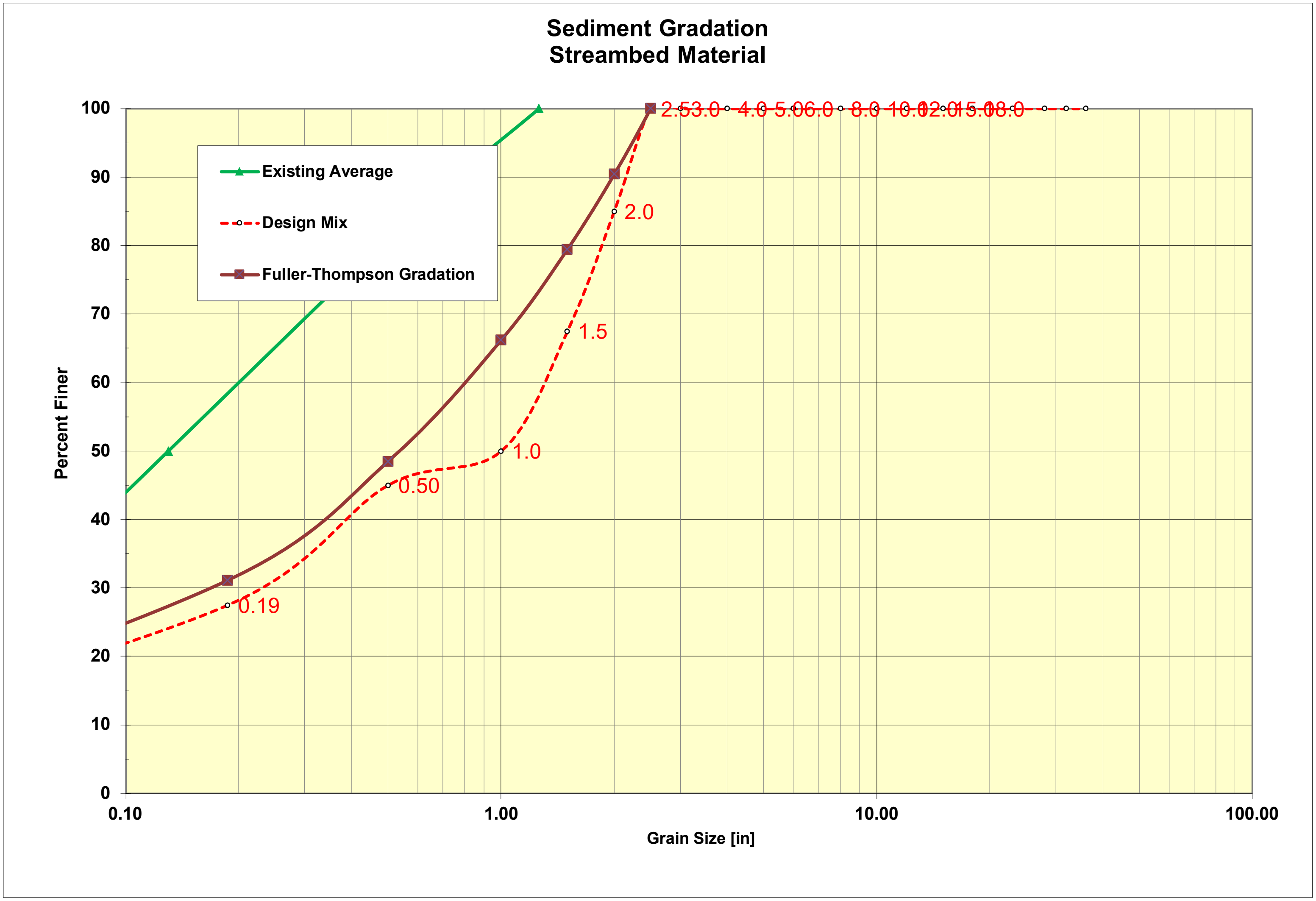
γ_s =	165	specific weight of sediment particle (lb/ft^3)
γ =	62.4	specific weight of water (lb/ft^3)
τ_{D50} =	0.047	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

τ_{ci} = the critical shear stress at which the sediment particle of interest begins to move (lb/ft^2 or N/m^2)

Average Modeled Shear Stress (lb/ft^2)

Rock Size [in]	D_{size}	τ_{ci}	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
			0.20	0.29	0.34	0.38	0.47	0.48
36.0	100.0	1.18	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
32.0	100.0	1.14	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
28.0	100.0	1.09	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
23.0	100.0	1.03	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
18.0	100.0	0.96	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
15.0	100.0	0.91	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
12.0	100.0	0.85	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
10.0	100.0	0.80	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
8.0	100.0	0.75	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
6.0	100.0	0.69	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.0	100.0	0.65	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.0	100.0	0.61	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.0	100.0	0.56	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.5	100.0	0.53	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.0	85.0	0.49	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.5	67.5	0.45	No Motion	No Motion	No Motion	No Motion	Motion	Motion
1.0	50.0	0.40	No Motion	No Motion	No Motion	No Motion	Motion	Motion
0.5	45.0	0.33	No Motion	No Motion	Motion	Motion	Motion	Motion
0.2	27.5	0.24	No Motion	Motion	Motion	Motion	Motion	Motion
0.0	10.0	0.12	Motion	Motion	Motion	Motion	Motion	Motion
0.0	5.0	0.07	Motion	Motion	Motion	Motion	Motion	Motion

D_{50} =	**1.00**	in	D_{95} =	**2.33**	in
	0.08	ft		0.19	ft
	25.4	mm		59.3	mm



Fuller-Thompson Gradation

Dmax = 2.50

Rock Size [in]	D_{size}
36.0	332.1
32.0	315.0
28.0	296.6
23.0	271.5
18.0	243.1
15.0	224.0
12.0	202.6
10.0	186.6
8.0	168.8
6.0	148.3
5.0	136.6
4.0	123.6
3.0	108.6
2.5	100.0
2.0	90.4
1.5	79.5
1.0	66.2
0.5	48.5
0.2	31.1
0.02	10.5
0.003	4.8

Summary - Boulder Cluster Design

Project:	**Big Scandia Creek, SR 308 MP 0.94, WDFW ID 990235**
By:	**David Evans and Associates; Chad Booth, PE**

Design Gradation

Location: Proposed Channel

	D_{100}	D_{84}	D_{50}	D_{16}
ft	1.5	1.4	1.3	1.1
in	18.0	17.0	15.0	13.0
mm	457	433	381.0	329.2

Existing Gradation

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0.0	0.0

Existing Gradation

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0.0	0.0

Existing Gradation

Location: Existing Average

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.1	0.0	0.0	0.0
in	1.3	0.6	0.1	0.0
mm	32	14	3.3	0.8

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			50.0
12.0	305						100				0.0
10.0	254					100	80				0.0
8.0	203				100	80	68				0.0
6.0	152			100	80	68	57				0.0
5.0	127			80	68	57	45				0.0
4.0	102		100	71	57	45	39				0.0
3.0	76.2		80	63	45	38	34				0.0
2.5	63.5	100	63	54	37	32	28				0.0
2.0	50.8	85	47	45	29	25	22				0.0
1.5	38.1	68	30	32	21	18	16				0.0
1.0	25.4	50	20	18	13	12	11				0.0
0.50	12.7	45	5	5	5	5	5				0.0
0.19	4.75	28									0.0
0.02	0.425	10									0.0
0.003	0.0750	5									0.0
% per category		0	0	0	0	0	0	100	0	0	*--> 100%*
% Cobble & Sediment		0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	*100.0%*

Boulder Cluster Mobility/Stability Analysis

Modified Shields Approach

References:

United States Forest Service (USFS)

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

Appendix E - Methods for Streambed Mobility/Stability Analysis

Range of Suitability:

$D_{84\ ranging}$ between 0.40 in and 10 in

Uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s = 165 specific weight of sediment particle (lb/ft^3)

γ = 62.4 specific weight of water (lb/ft^3)

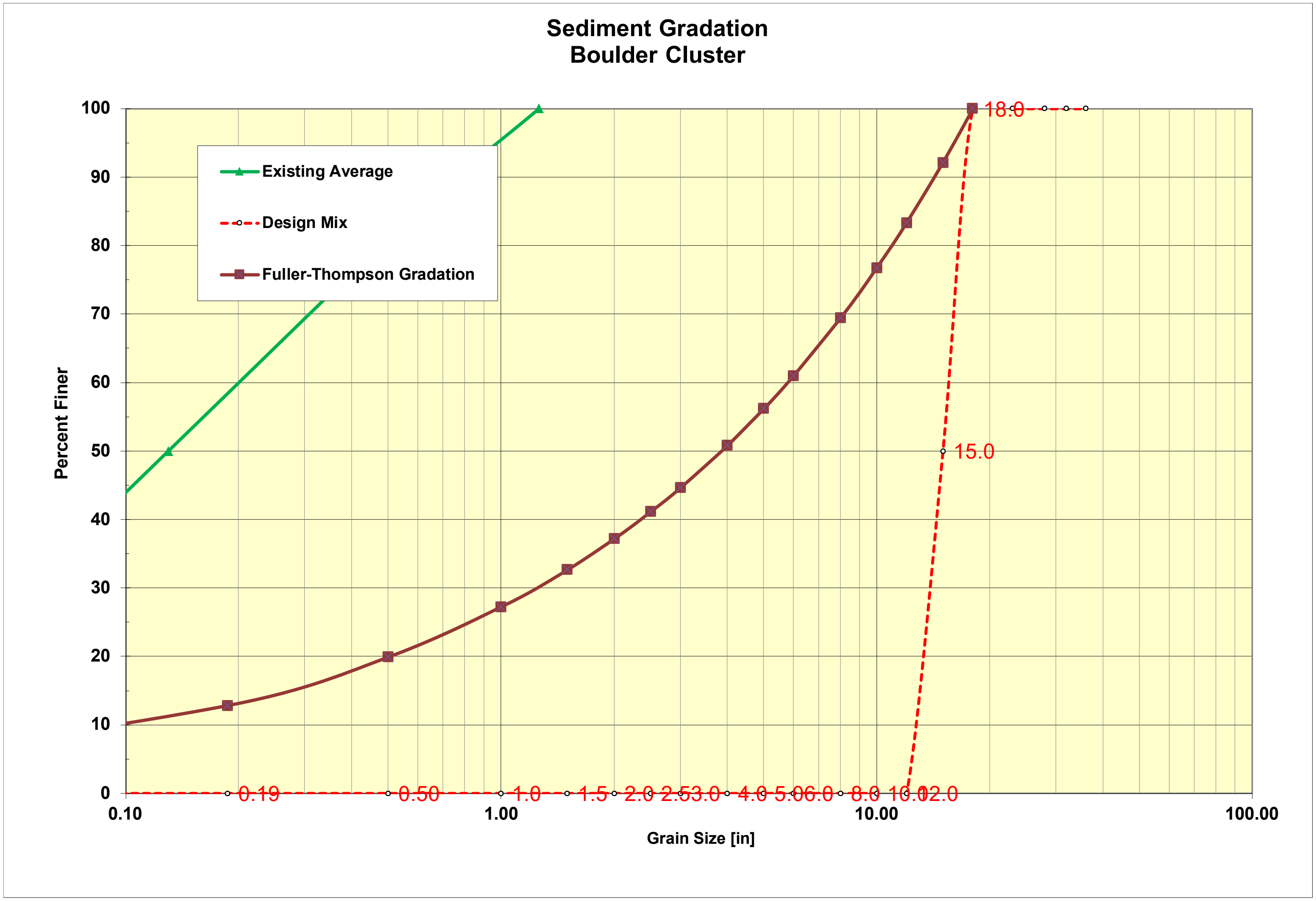
τ_{D50} = 0.054 dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

τ_{ci} = the critical shear stress at which the sediment particle of interest begins to move (lb/ft^2 or N/m^2)

Average Modeled Shear Stress (lb/ft^2)

Rock Size [in]	D_{size}	τ_{ci}	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
			0.20	0.29	0.34	0.38	0.47	0.48
36.0	100.0	9.01	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
32.0	100.0	8.69	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
28.0	100.0	8.35	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
23.0	100.0	7.87	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
18.0	100.0	7.31	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
15.0	50.0	6.93	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
12.0	0.0	6.48	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
10.0	0.0	6.13	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
8.0	0.0	5.74	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
6.0	0.0	5.26	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.0	0.0	4.98	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.0	0.0	4.66	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.0	0.0	4.27	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.5	0.0	4.05	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.0	0.0	3.78	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.5	0.0	3.47	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.0	0.0	3.07	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
0.5	0.0	2.50	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
0.2	0.0	1.86	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
0.0	0.0	0.90	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
0.0	0.0	0.54	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion

D_{50} =	**15.00**	in	D_{95} =	**17.70**	in
	1.25	ft		1.48	ft
	381.0	mm		449.6	mm

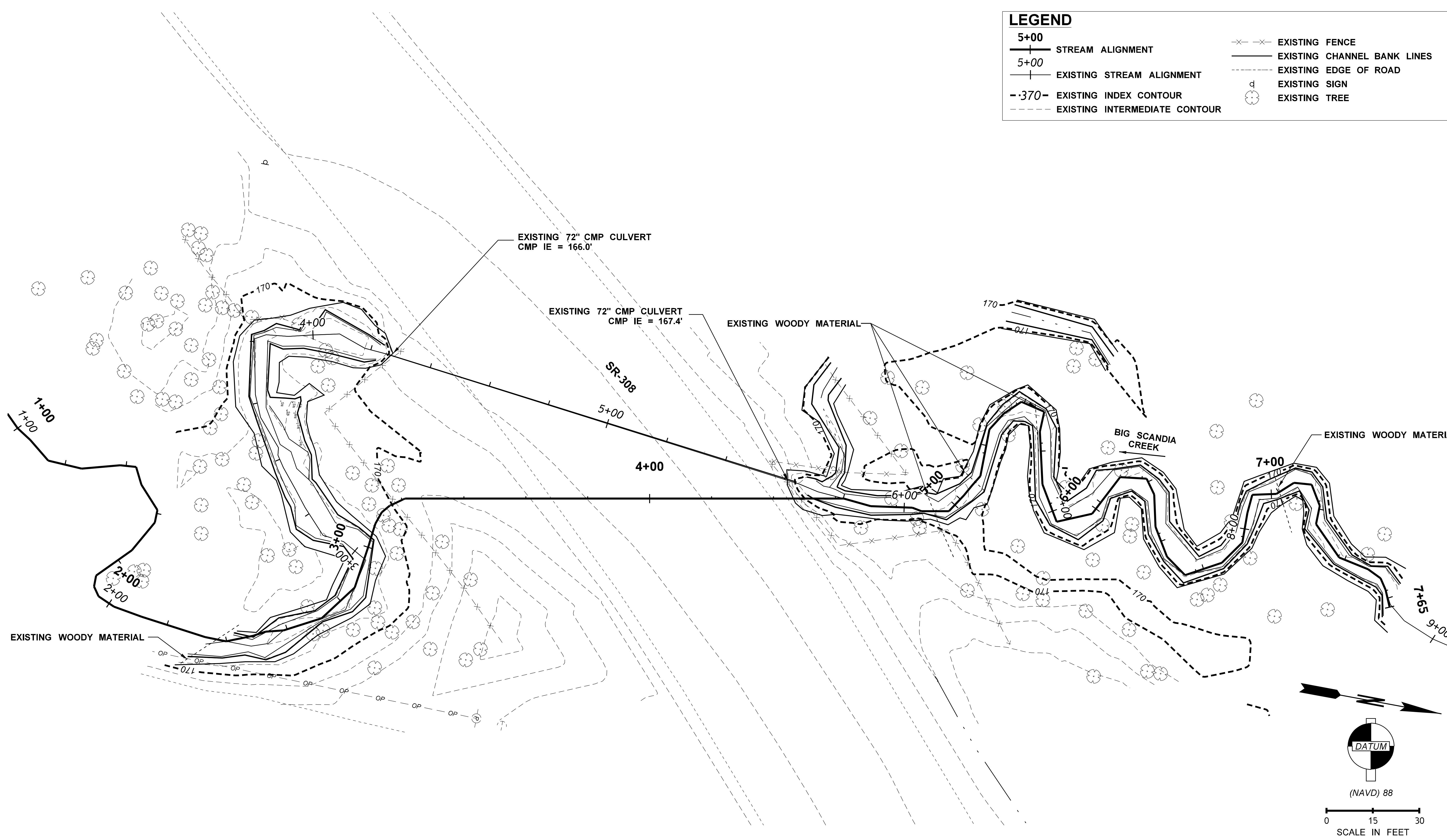


Fuller-Thompson Gradation

Dmax = 18.00

Rock Size [in]	D_{size}
36.0	136.6
32.0	129.6
28.0	122.0
23.0	111.7
18.0	100.0
15.0	92.1
12.0	83.3
10.0	76.8
8.0	69.4
6.0	61.0
5.0	56.2
4.0	50.8
3.0	44.7
2.5	41.1
2.0	37.2
1.5	32.7
1.0	27.2
0.5	19.9
0.2	12.8
0.02	4.3
0.003	2.0

Appendix D: Stream Plan Sheets, Profile, Details



FILE NAME	c:\users\kxto\pw_wsdot\d0463032\990235_PS_FP_CE_01.dgn			
TIME	3:34:32 PM			
DATE	12/28/2022			
PLOTTED BY	Kxto			
DESIGNED BY	C. BOOTH			
ENTERED BY	R. WILCOX			
CHECKED BY	-			
PROJ. ENGR.	-			
REGIONAL ADM.	-	REVISION	DATE	BY

REGION NO. | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

PRELIMINARY

NOT FOR CONSTRUCTION

DATE — P.E. STAMP BOX | DATE — P.E. STAMP BOX

Washington State Department of Transportation

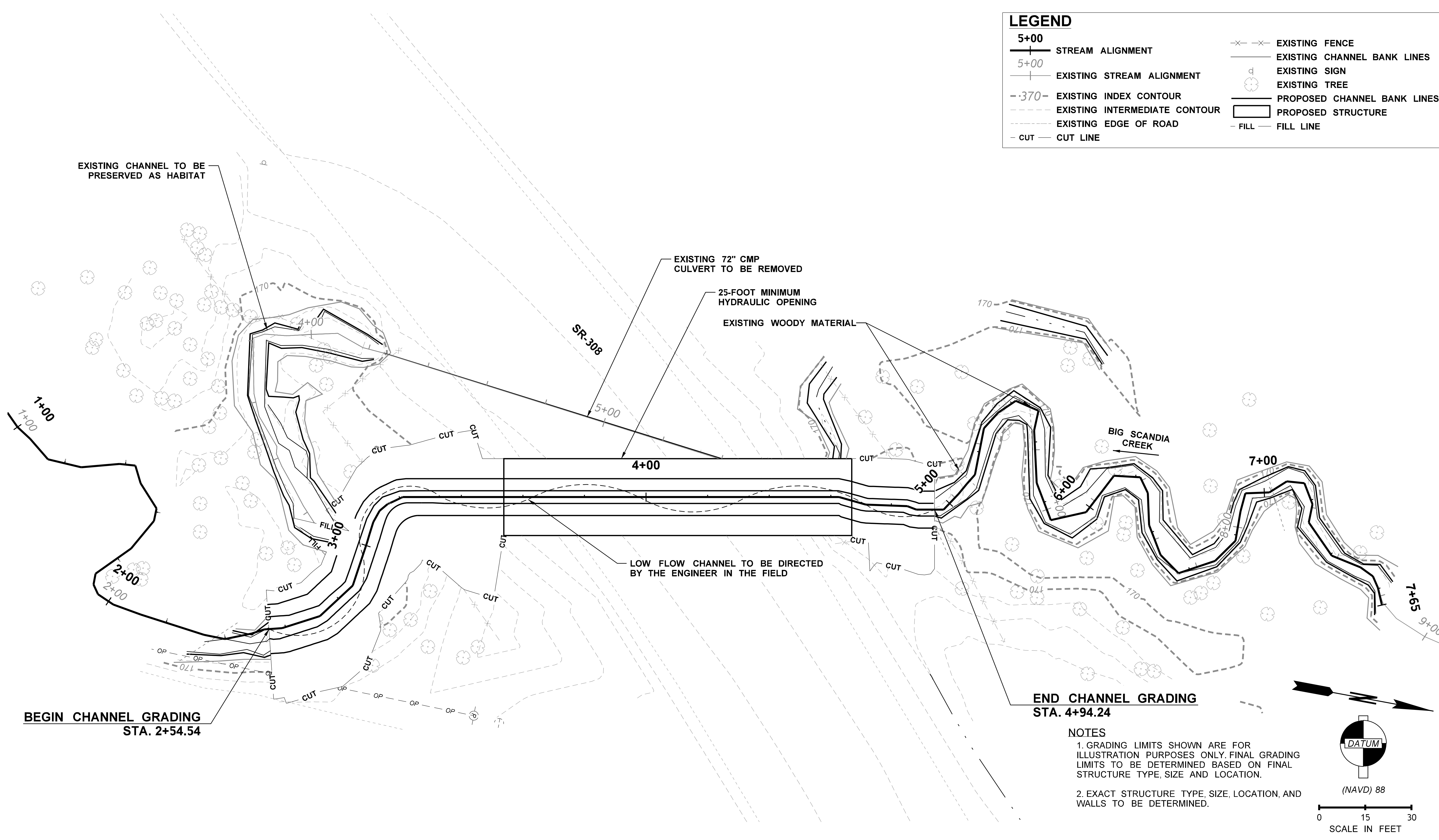
DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 00.94
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

EXISTING STREAM PLAN

PLAN REF NO

SHEET OF SHEETS



FILE NAME	c:\users\cgb\pw_wsdot\d0463032\990235_PS_FP_01.dgn			
TIME	4:36:04 AM			
DATE	12/29/2022			
PLOTTED BY	Cgb			
DESIGNED BY	C. BOOTH			
ENTERED BY	R. WILCOX			
CHECKED BY	-			
PROJ. ENGR.	-			
REGIONAL ADM.	-	REVISION	DATE	BY

REGION NO. | STATE: WASH | FED.AID PROJ.NO.
JOB NUMBER
CONTRACT NO. | LOCATION NO.

PRELIMINARY
NOT FOR CONSTRUCTION

DATE
P.E. STAMP BOX
DATE
P.E. STAMP BOX

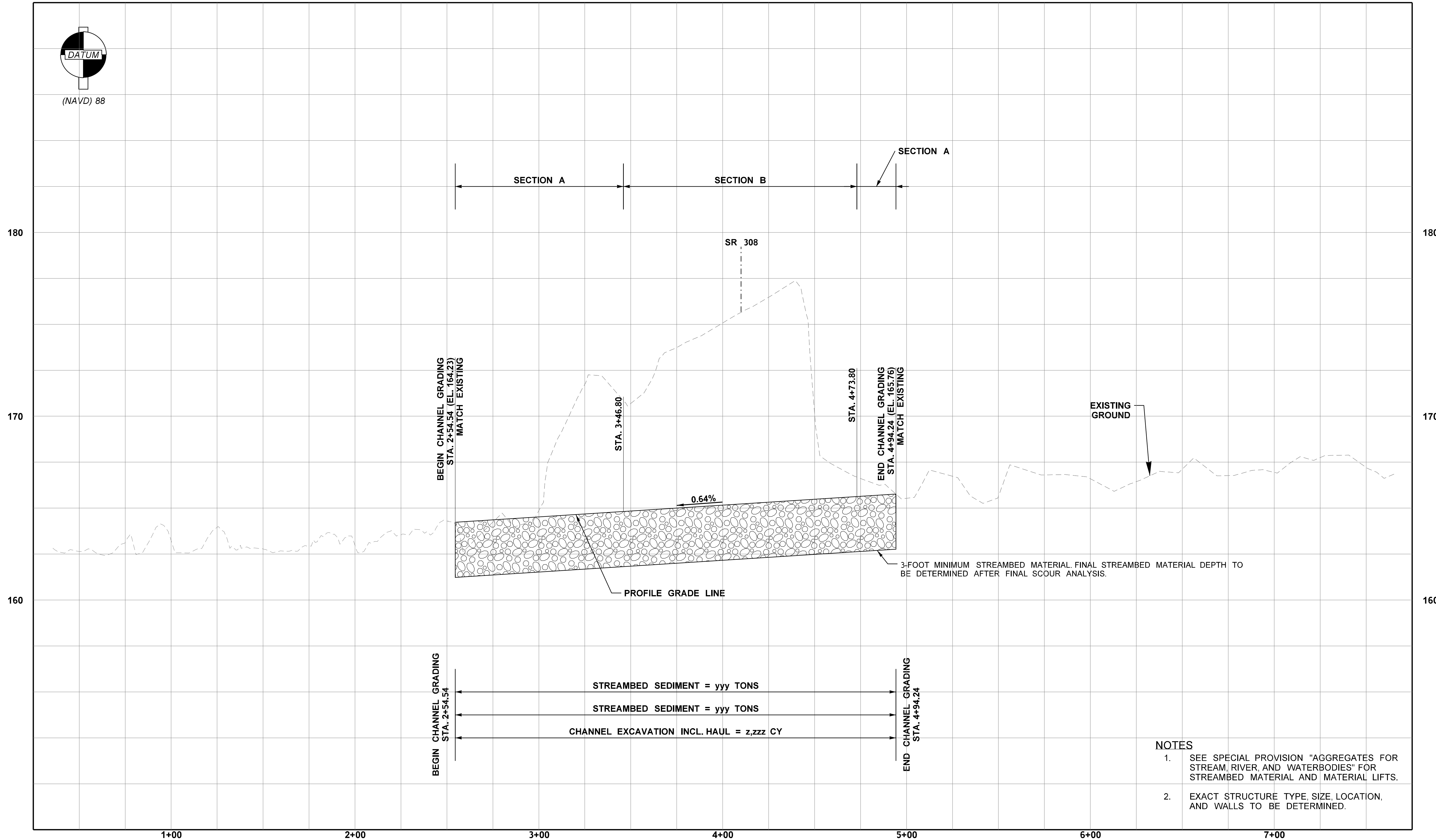
Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 00.94
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

PROPOSED STREAM PLAN

PLAN REF NO
SHEET
OF
SHEETS



NOTES

1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAM, RIVER, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
2. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

FILE NAME	c:\users\kxto\pw_wsdot\d0463032\990235_PR_FP_01.dgn
TIME	1:22:02 PM
DATE	12/28/2022
PLOTTED BY	Kxto
DESIGNED BY	C. BOOTH
ENTERED BY	R. WILCOX
CHECKED BY	-
PROJ. ENGR.	-
REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO. | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

PRELIMINARY

NOT FOR CONSTRUCTION

P.E. STAMP BOX DATE P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 00.94
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

STREAM PROFILE

PLAN REF NO

SHEET

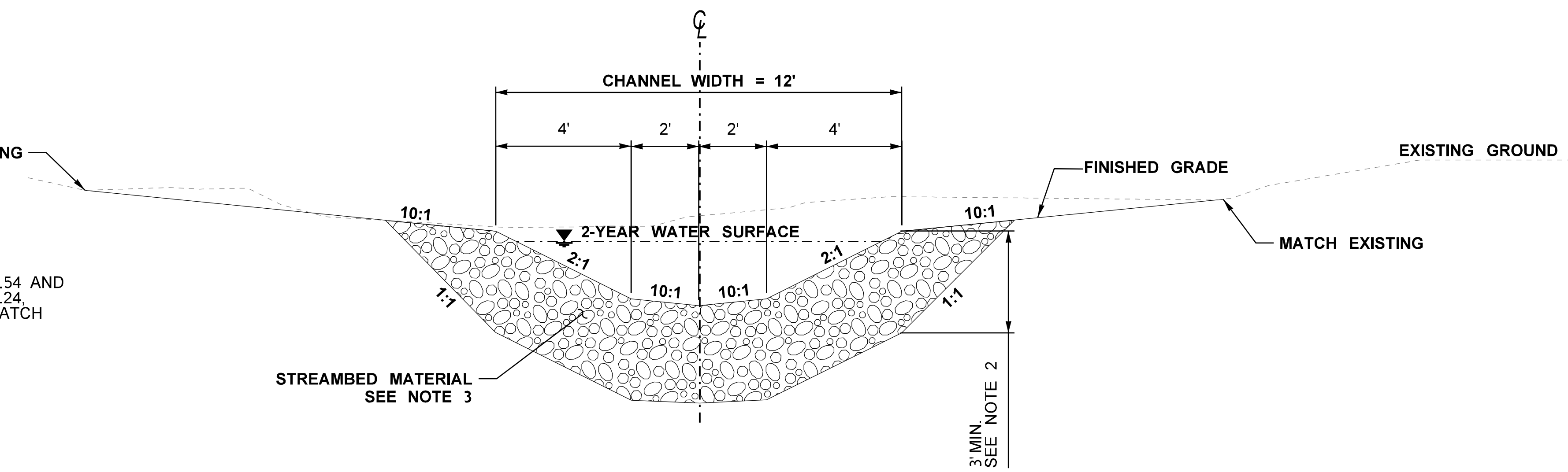
OF

SHEETS

SECTION A

STATION 2+54.54 TO 3+46.80
STATION 4+73.80 TO 4+94.24

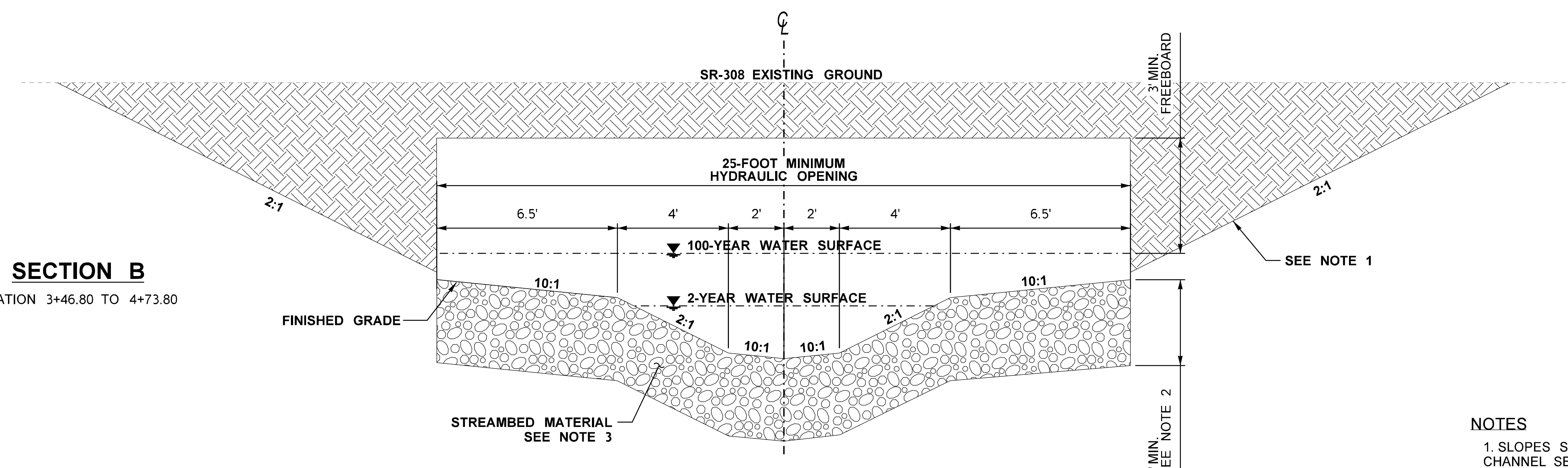
FROM STATION 2+54.54 TO 2+74.54 AND FROM STATION 4+74.24 TO 4+94.24, EVENLY TAPER SECTIONS TO MATCH EXISTING CHANNEL.



TYPICAL CHANNEL

SECTION B

STATION 3+46.80 TO 4+73.80



TYPICAL CHANNEL INSIDE STRUCTURE

NOTES

1. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.

2. MATERIAL DEPTH IS APPROXIMATE, FINAL DEPTH TO BE DETERMINED AFTER SCOUR ANALYSIS.

3. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.

FILE NAME	c:\users\kxto\pw_wsdot\d0463032\990235_DE_FP_01.dgn
TIME	12:55:53 PM
DATE	12/28/2022
PLOTTED BY	Kxto
DESIGNED BY	C. BOOTH
ENTERED BY	R. WILCOX
CHECKED BY	-
PROJ. ENGR.	-
REGIONAL ADM.	-

REVISION | DATE | BY

REGION NO. | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

PRELIMINARY

NOT FOR CONSTRUCTION

DATE
P.E. STAMP BOX
DATE
P.E. STAMP BOX

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 308 MP 00.94
LITTLE SCANDIA CREEK TO LIBERTY BAY
FISH BARRIER REMOVAL

STREAM DETAILS

PLAN REF NO

SHEET

OF

SHEETS

Appendix E: Manning's Calculations (NOT USED)

Appendix F: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR 308*		**Key piece volume**	***1.310***	*yd3*
Stream name	*Big Scandia Creek*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*240*	*ft*	**Total wood vol./ft**	***0.3948***	*yd3/ft stream*
Bankfull width	*12.5*	*ft*	**Total LWM**[c] **pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Log type	*Diameter at midpoint (ft)*	*Length(ft)* [d]	*Volume (yd^3 /log)* [d]	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*
A	2.00	*30*	3.49	**yes**	yes	3	10.47
B	2.00	*20*	2.33	**no**	yes	5	11.64
C	1.50	*20*	1.31	**no**	no	8	10.47
D	1.00	*15*	0.44	**yes**	no	12	5.24
E			0.00				0.00
F			0.00				0.00
G			0.00				0.00
H			0.00				0.00
I			0.00				0.00
J			0.00				0.00
K			0.00				0.00
L			0.00				0.00
M			0.00				0.00
N			0.00				0.00
O			0.00				0.00
P			0.00				0.00

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd^3)**
Design	8	28	37.8
Targets	**8**	**28**	**94.8**
	on target	on target	deficit

[a] **includes length through crossing, regardless of structure type**

[b] **choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information**

Western Washington lowla (generally <4,200 ft. in elevation west of the Cascade Crest)

Alpine (generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)

Douglas fir-Ponderosa pine (mainly east slope Cascades below 3,700 ft. elevation)

[c]**LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).**

[d]**includes rootwad if present**

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: GEC Bundle 1 PHD

Stream Name: Big Scandia Cr SR 3 MP 49.48

Drainage Area: 261 ac

Projected mean percent change in bankfull flow:

2040s: 14.4%

2080s: 17.4%

Projected mean percent change in bankfull width:

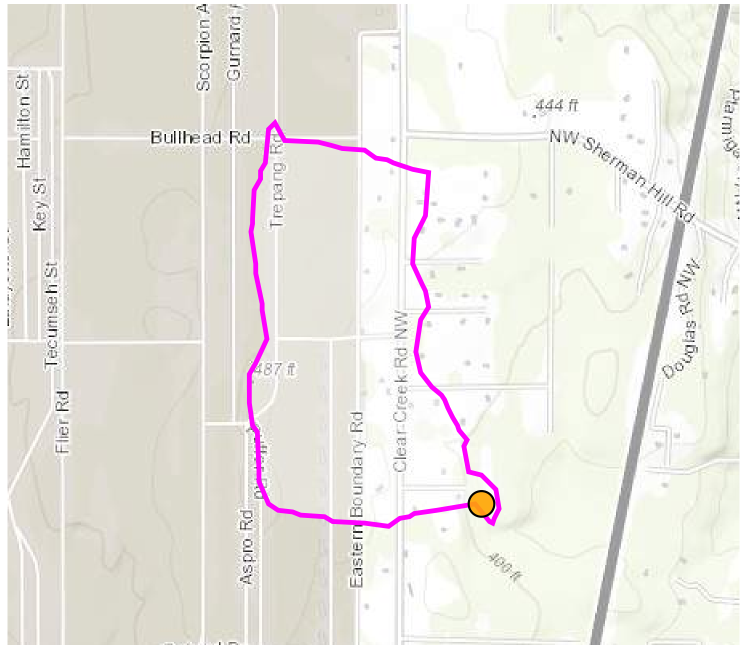
2040s: 6.9%

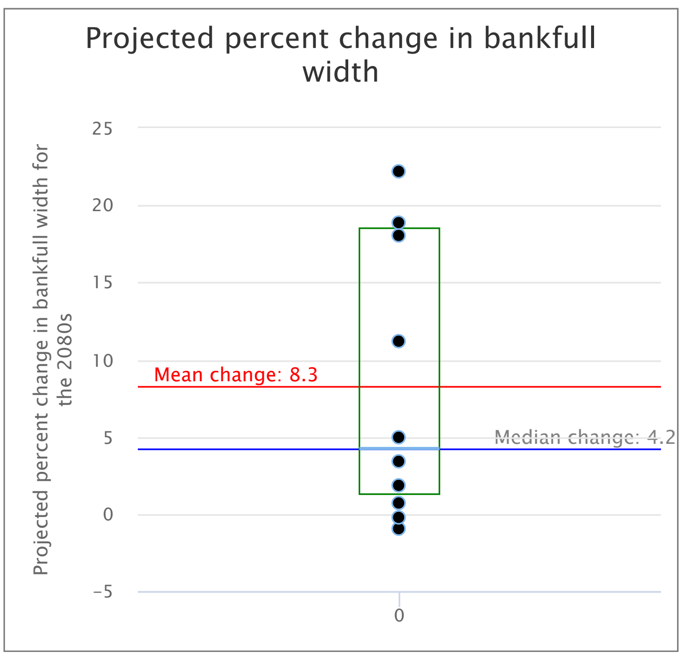
2080s: 8.3%

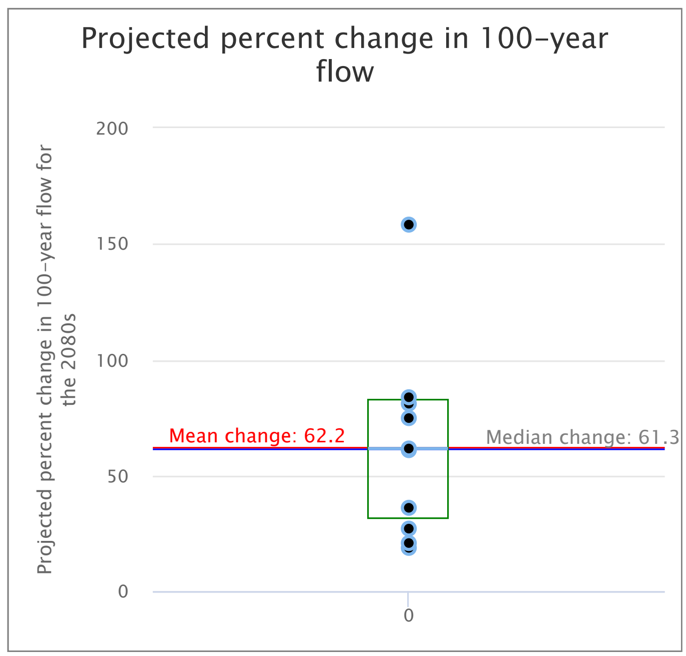
Projected mean percent change in 100-year flood:

2040s: 45.2%

2080s: 62.2%







Black dots are projections from 10 separate models

*An adjacent project site to Big Scandia Creek 990235 was used as the web application for future climate projections could not delineate a basin at SR 308 MP 0.94.

Appendix H: SRH-2D Model Results

Existing Conditions SRH-2D Results

Planview

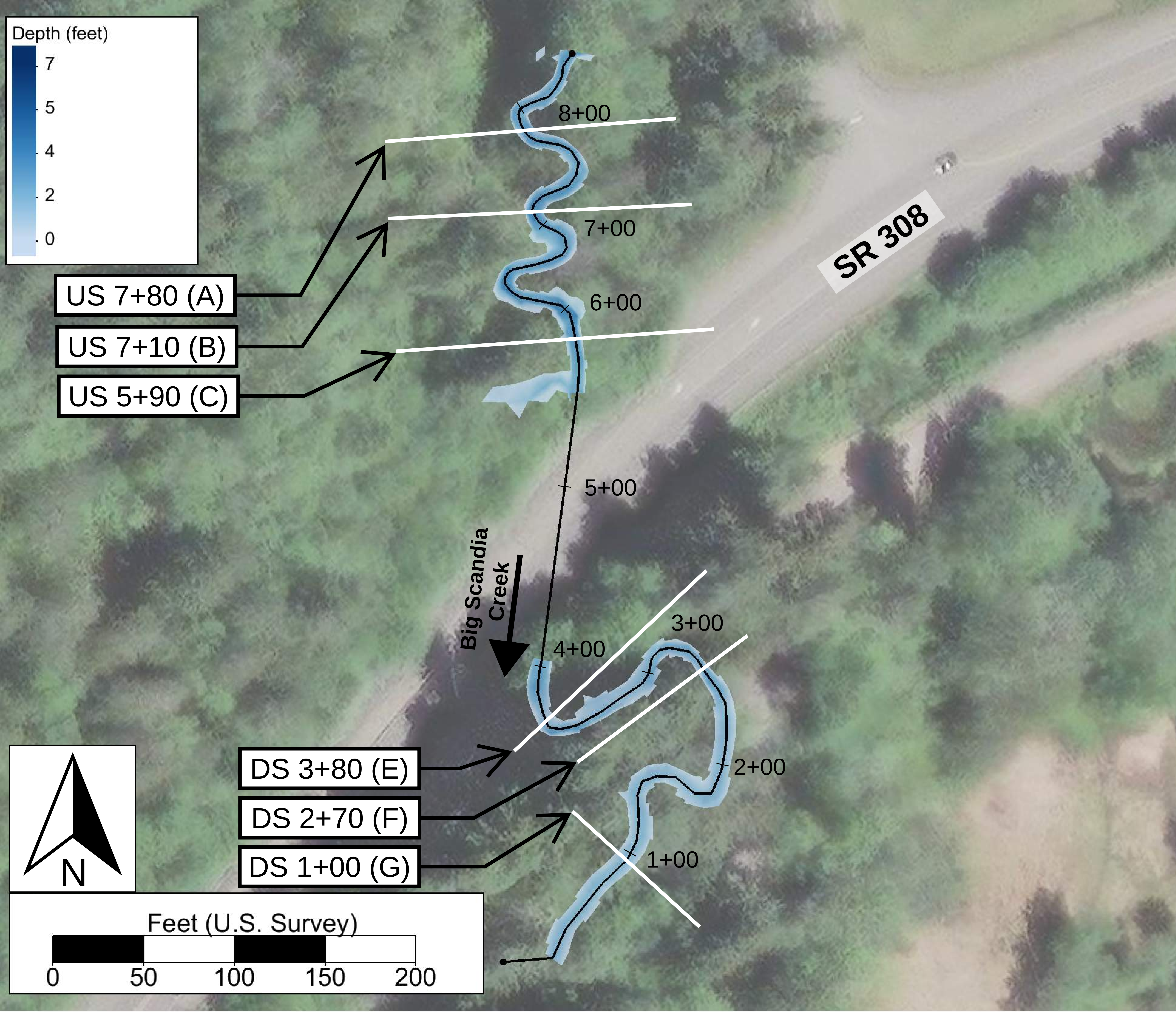


Figure H.1: Existing conditions 2-year depth

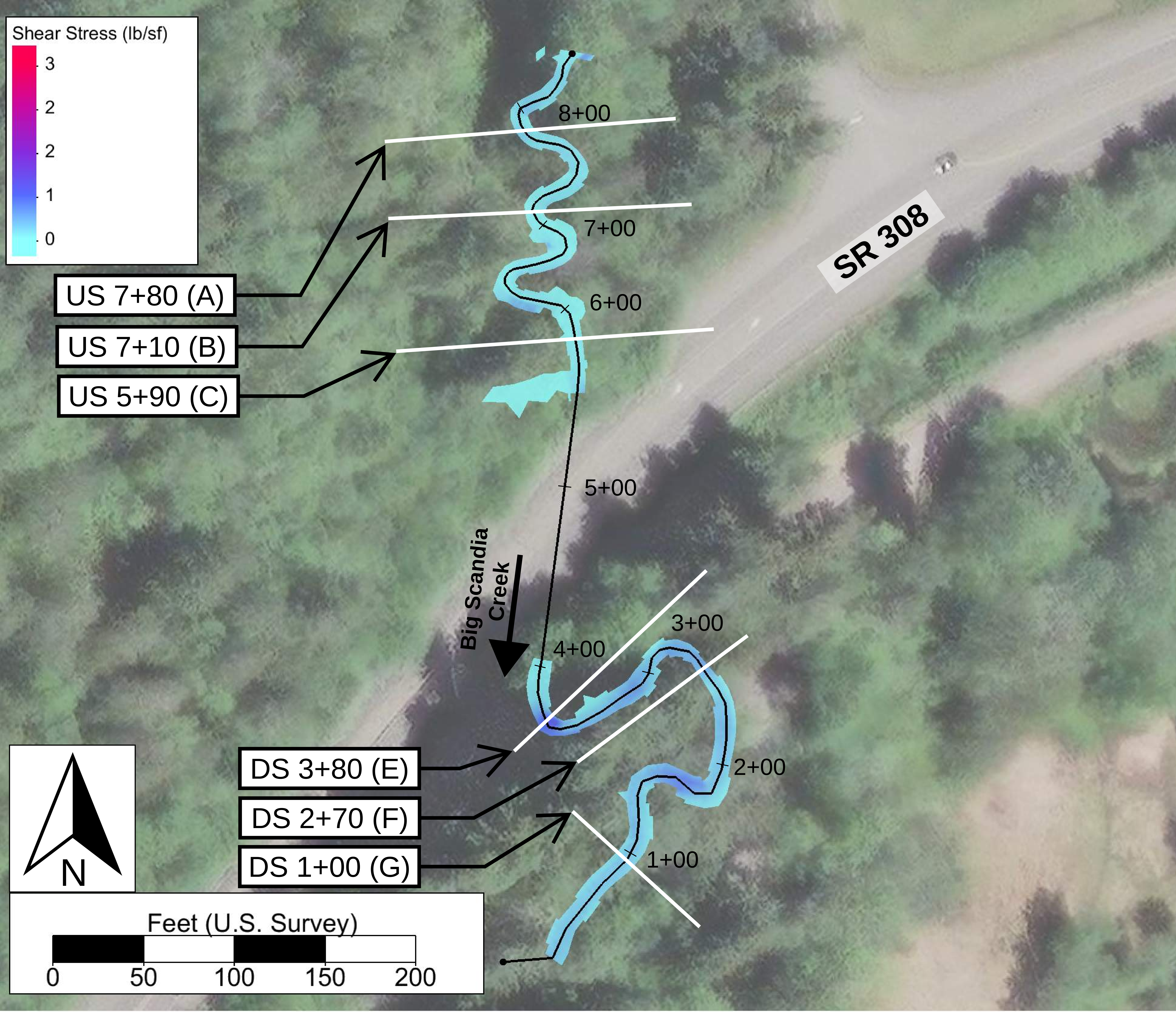


Figure H.2: Existing conditions 2-year shear stress

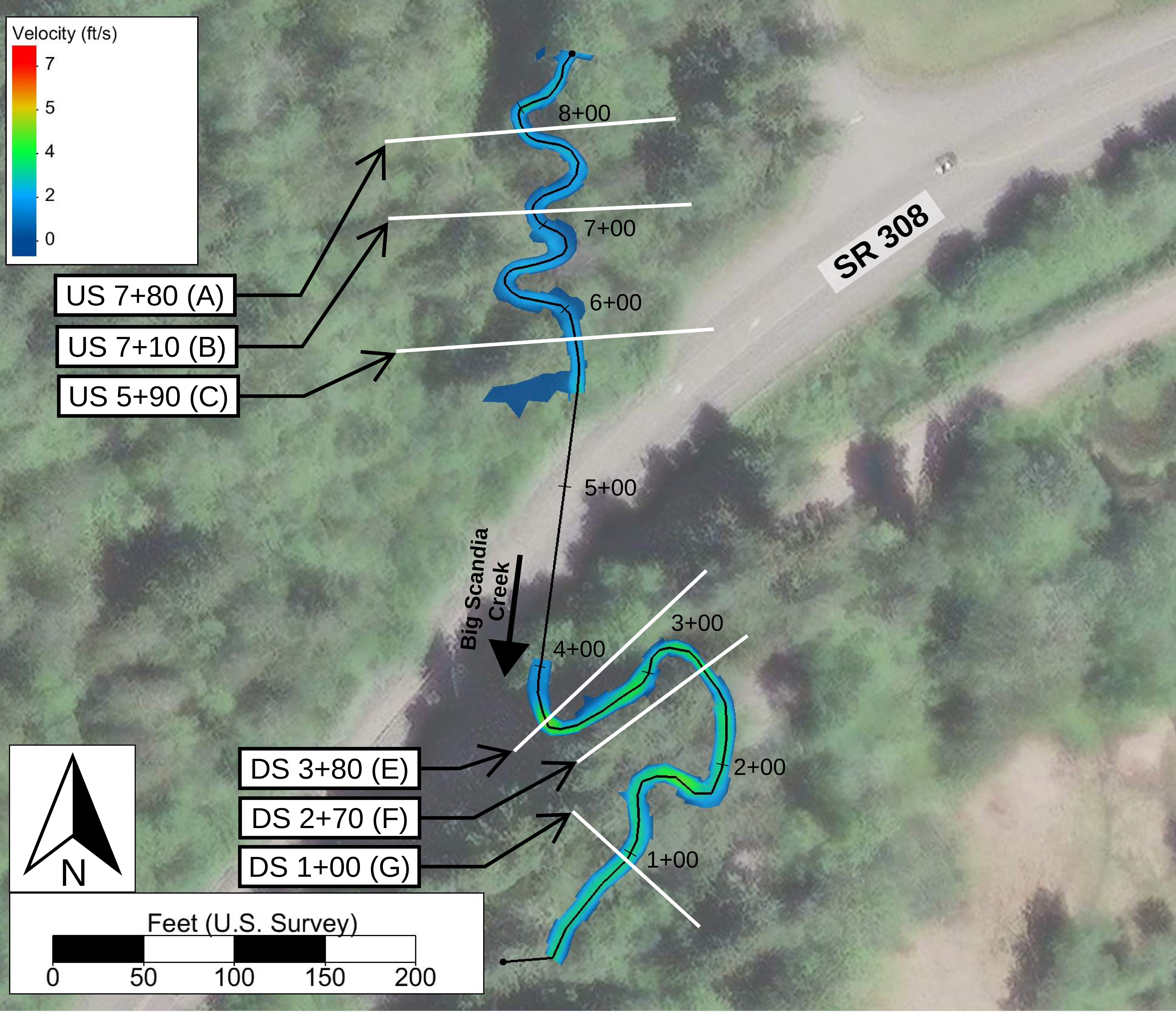


Figure H.3: Existing conditions 2-year velocity

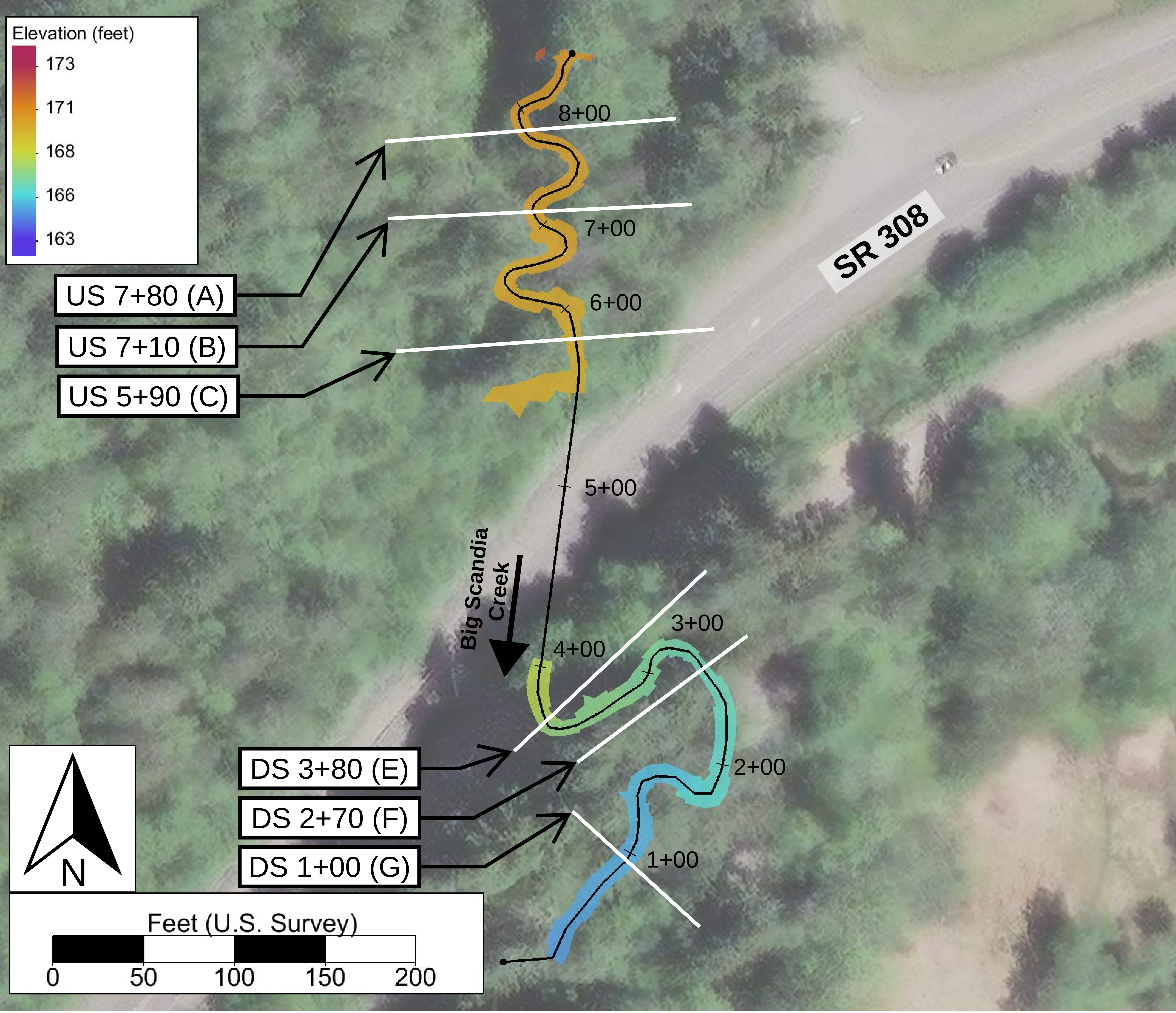


Figure H.4: Existing conditions 2-year water surface elevation

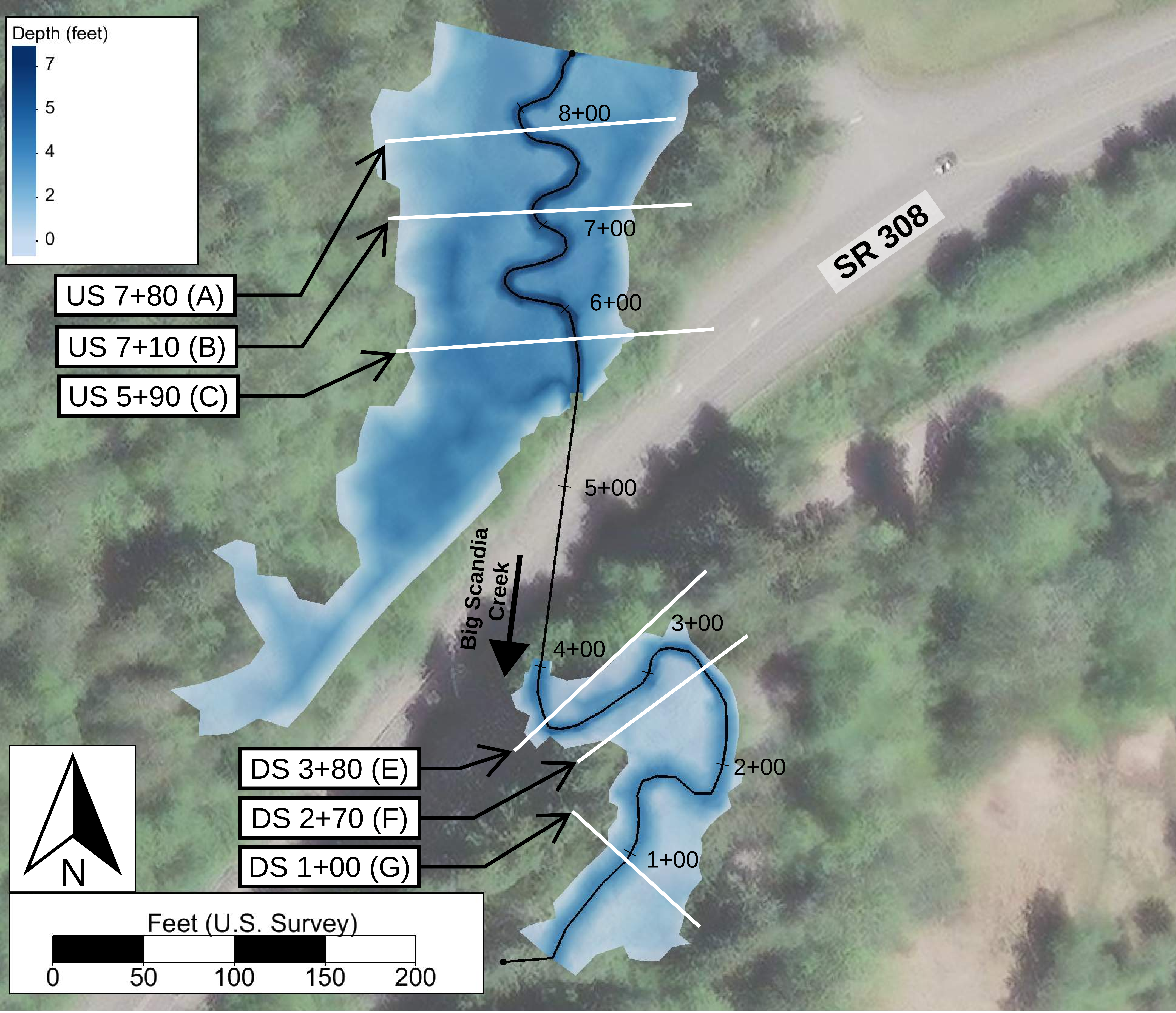


Figure H.5: Existing conditions 100-year depth

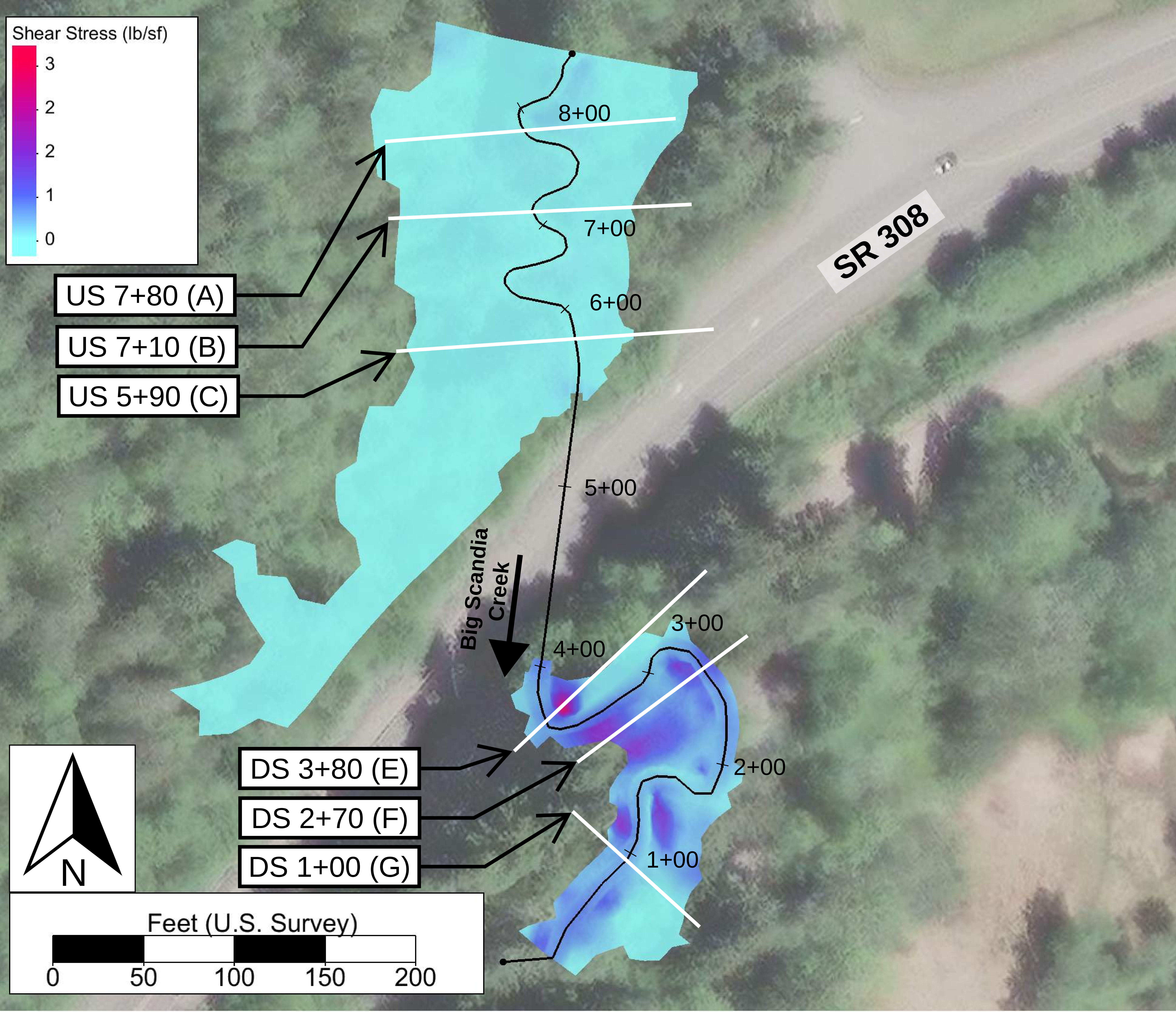


Figure H.6: Existing conditions 100-year shear stress

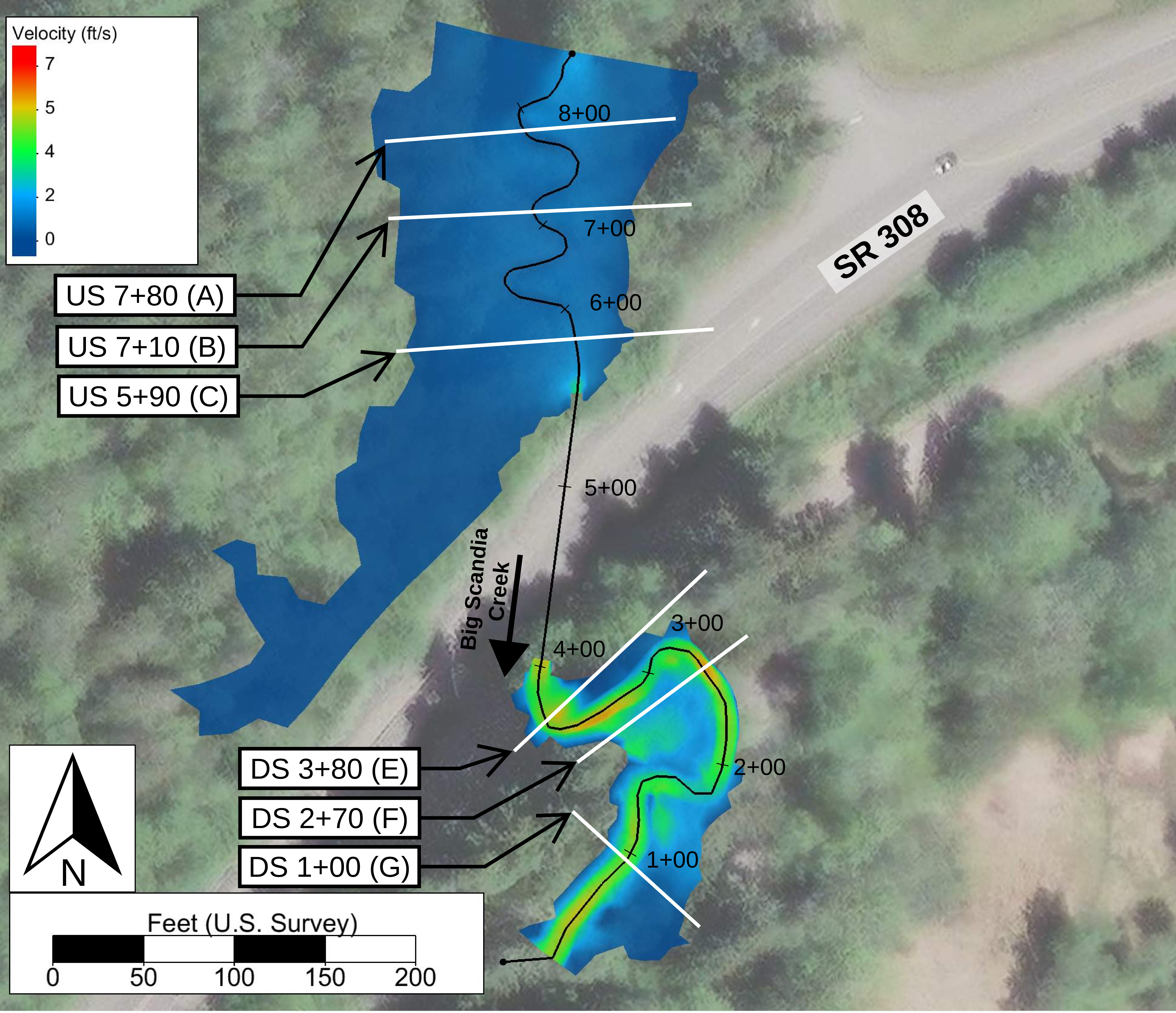


Figure H.7: Existing conditions 100-year velocity

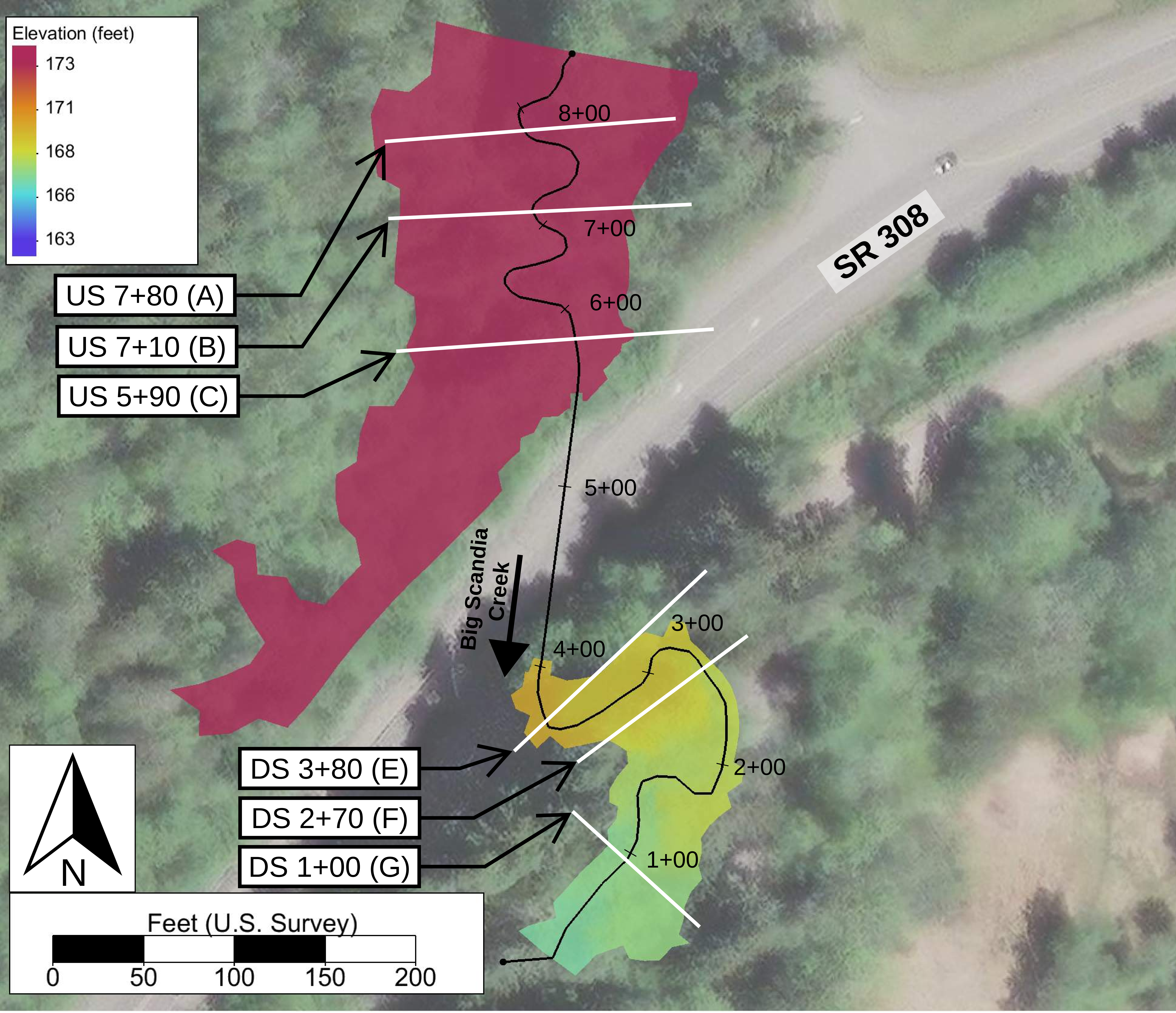


Figure H.8: Existing conditions 100-year water surface elevation

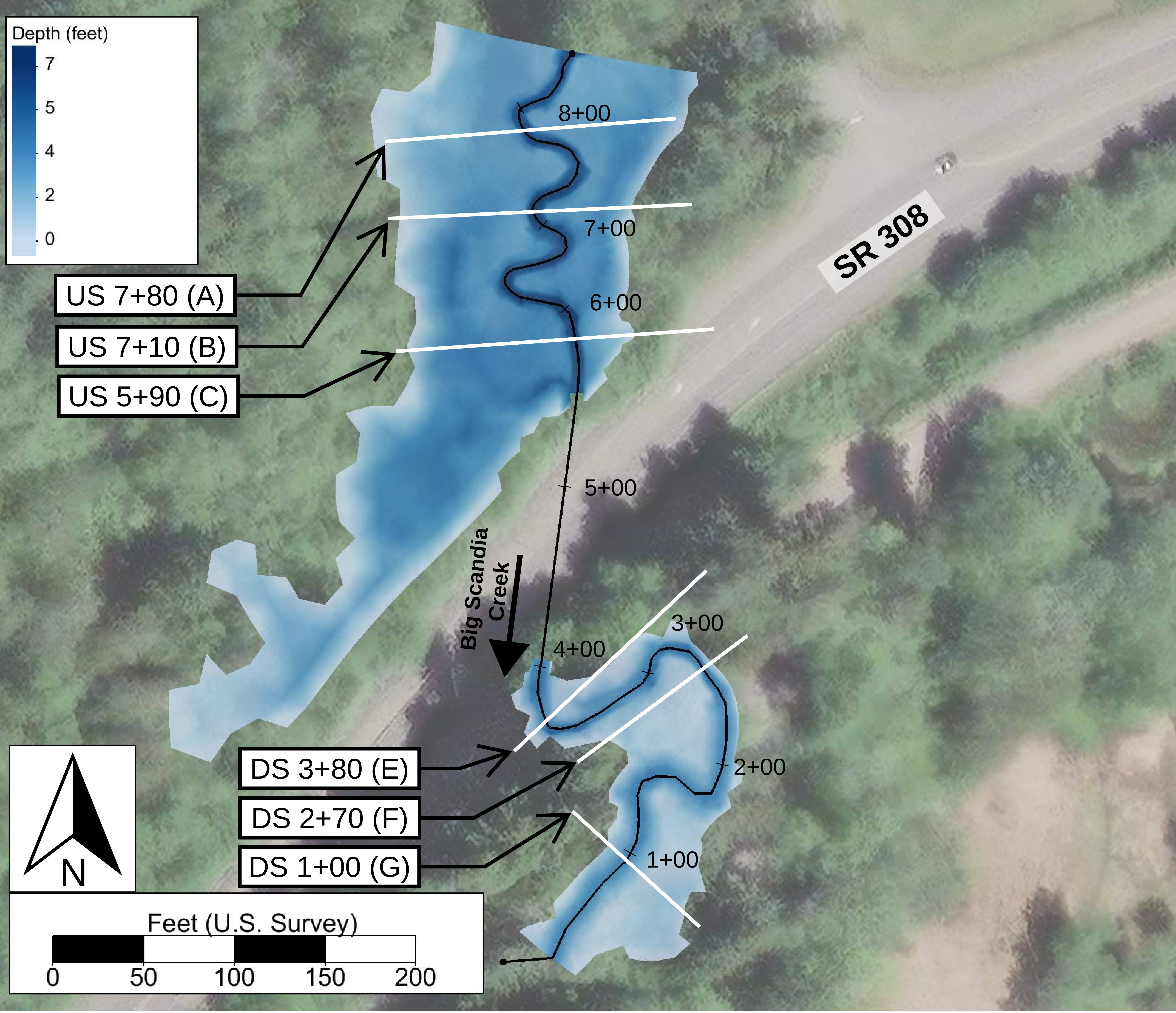


Figure H.9: Existing conditions 500-year depth

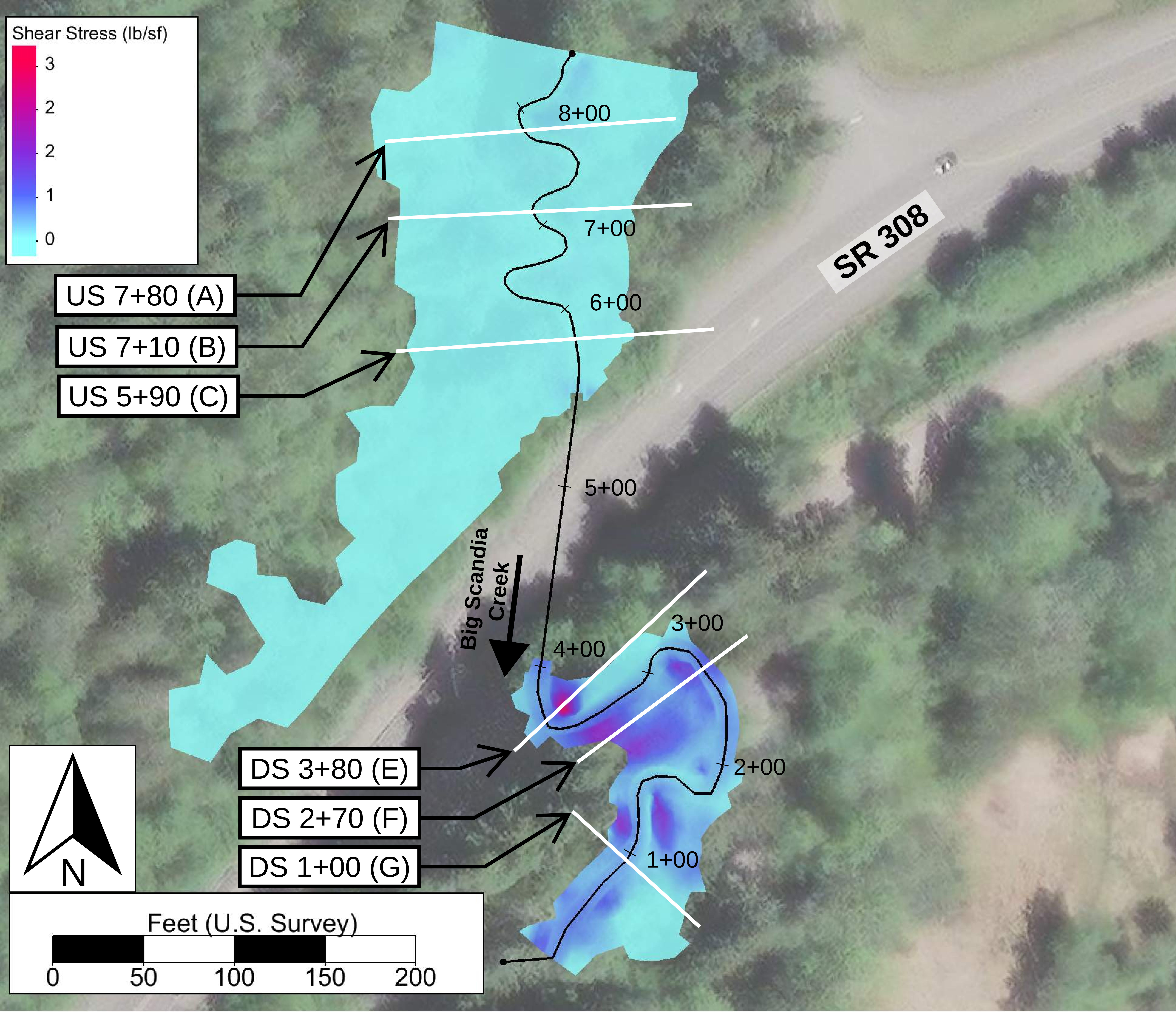


Figure H.10: Existing conditions 500-year shear stress

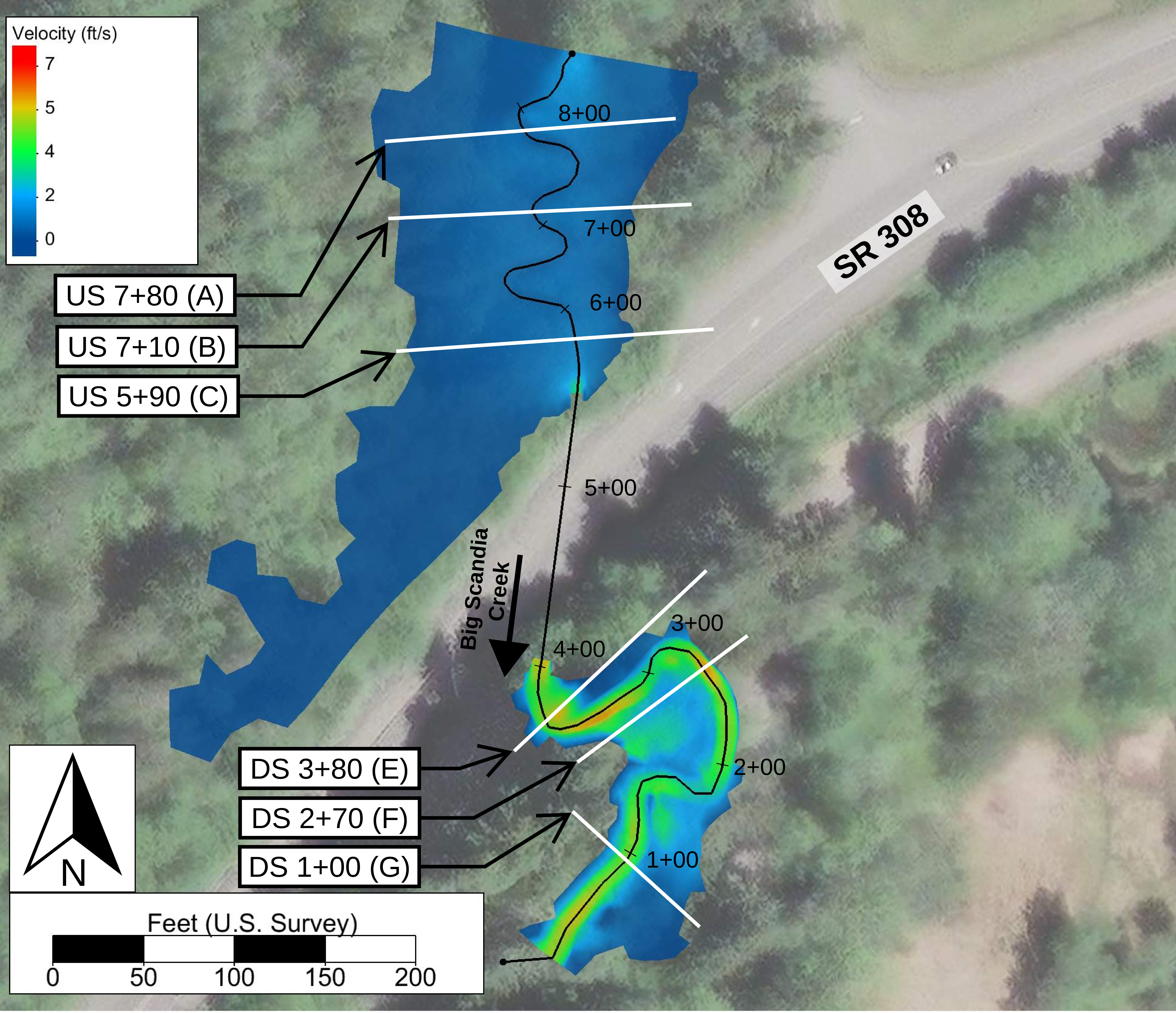


Figure H.11: Existing conditions 500-year velocity

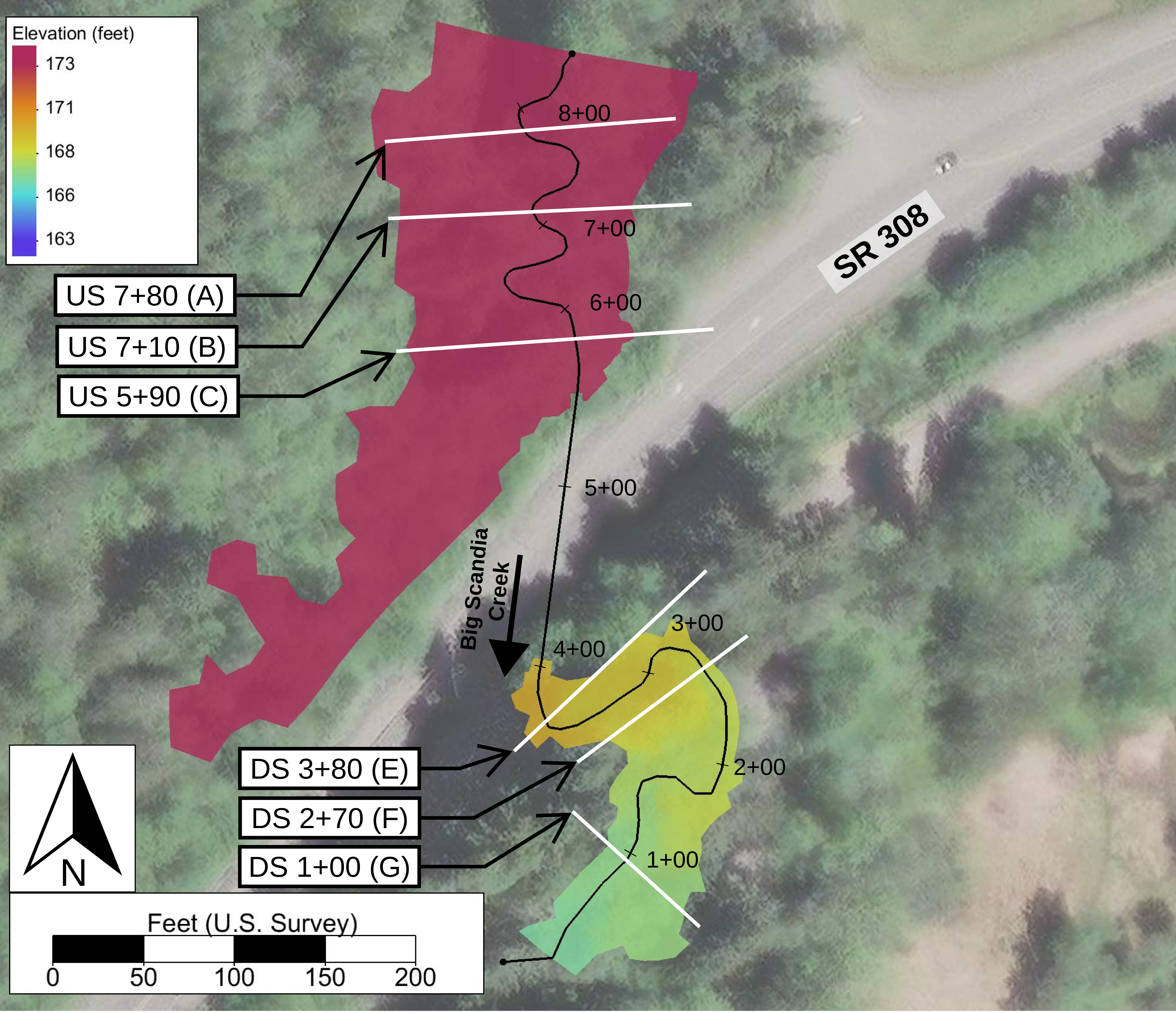


Figure H.12: Existing conditions 500-year water surface elevation

Natural Conditions SRH-2D Results

Planview

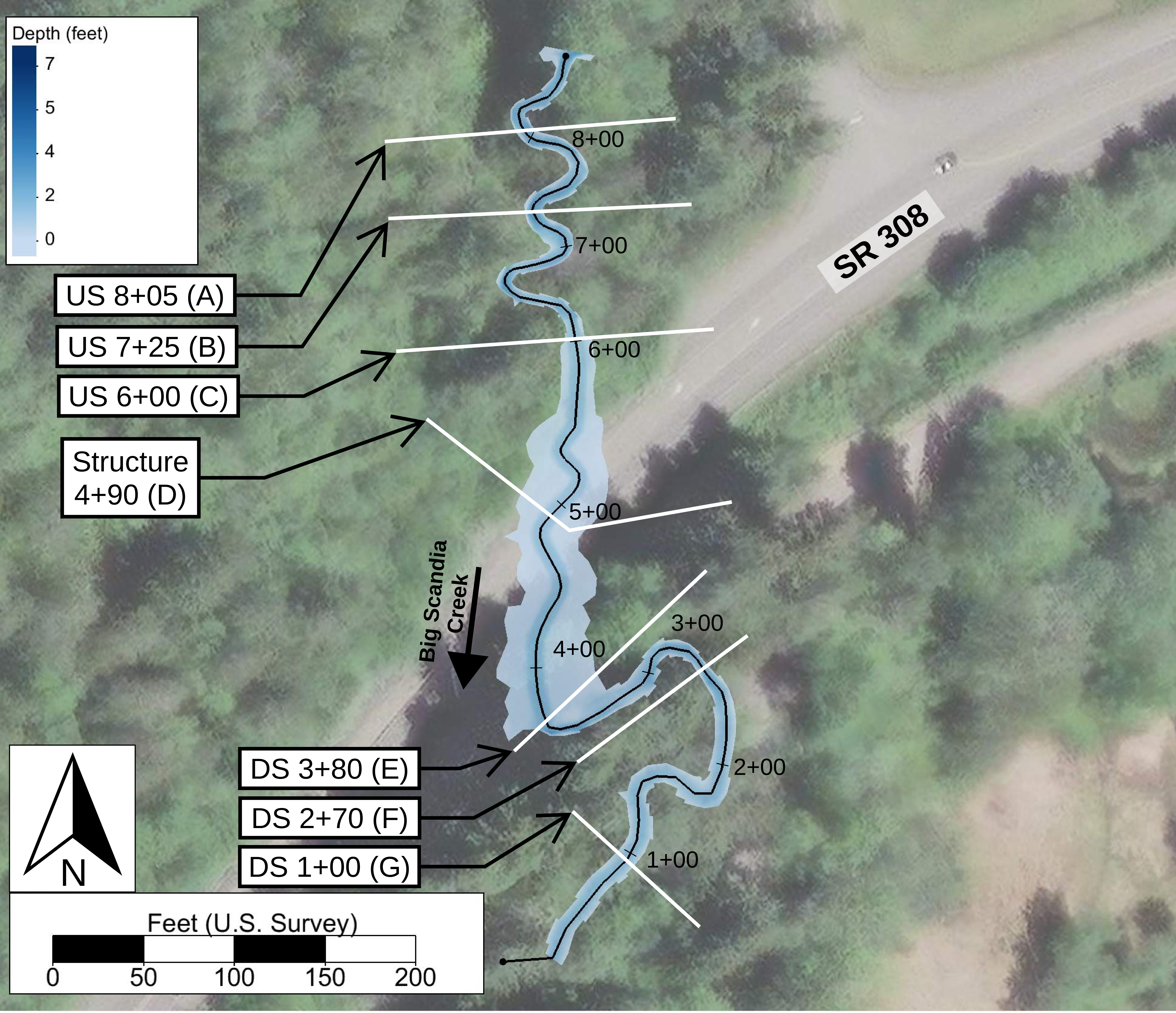


Figure H.13: Natural conditions 2-year depth

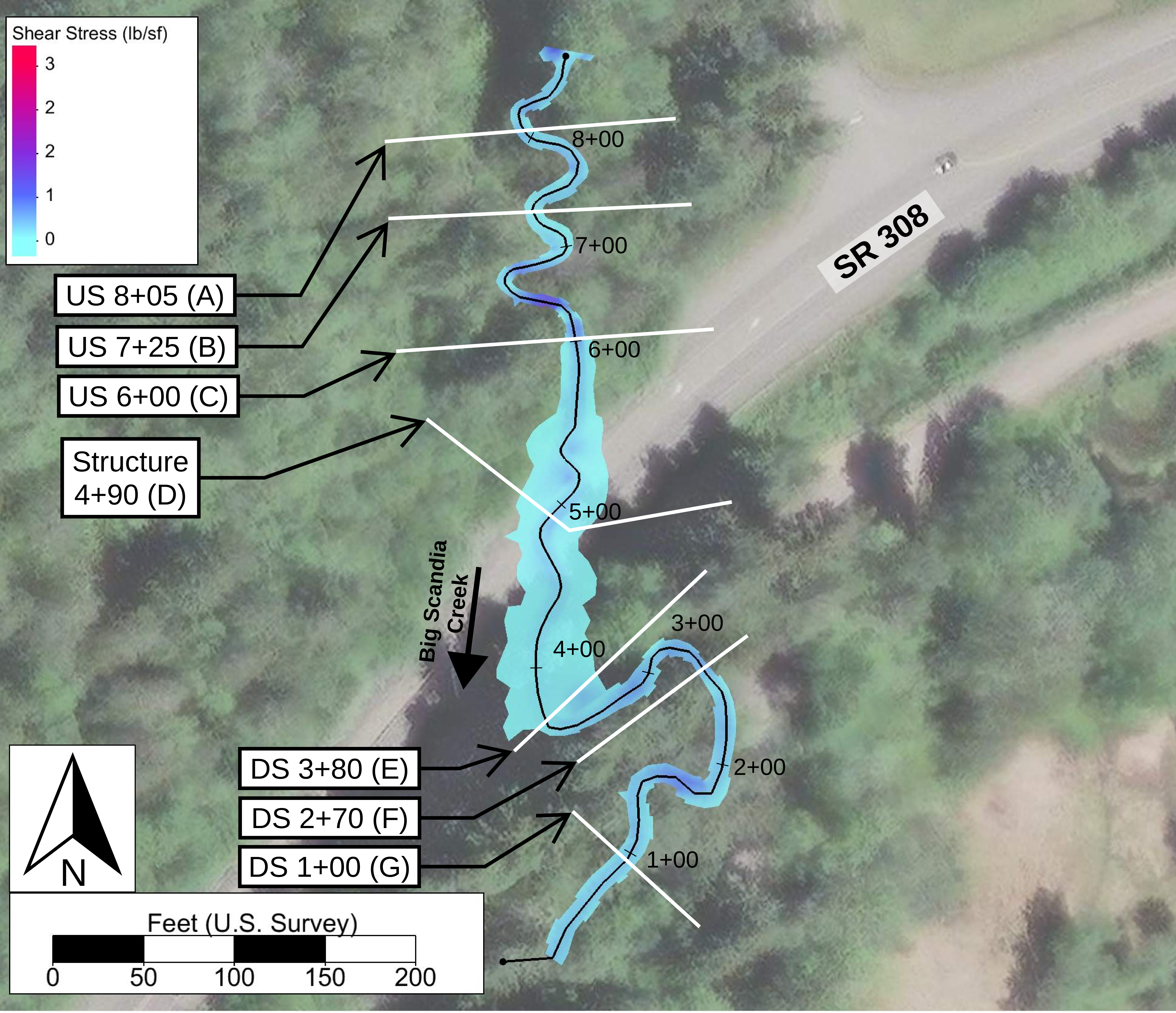


Figure H.14: Natural conditions 2-year shear stress

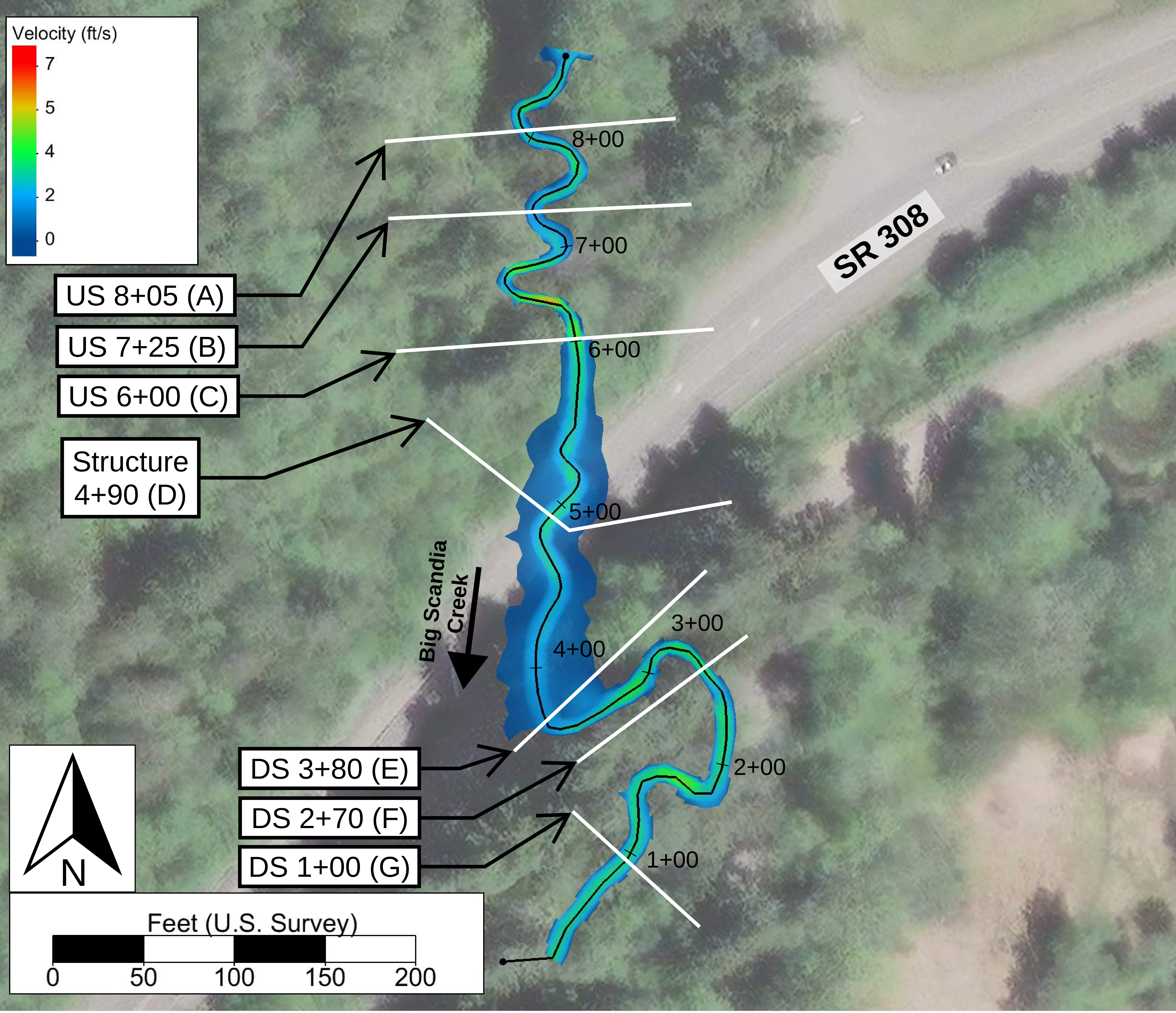


Figure H.15: Natural conditions 2-year velocity

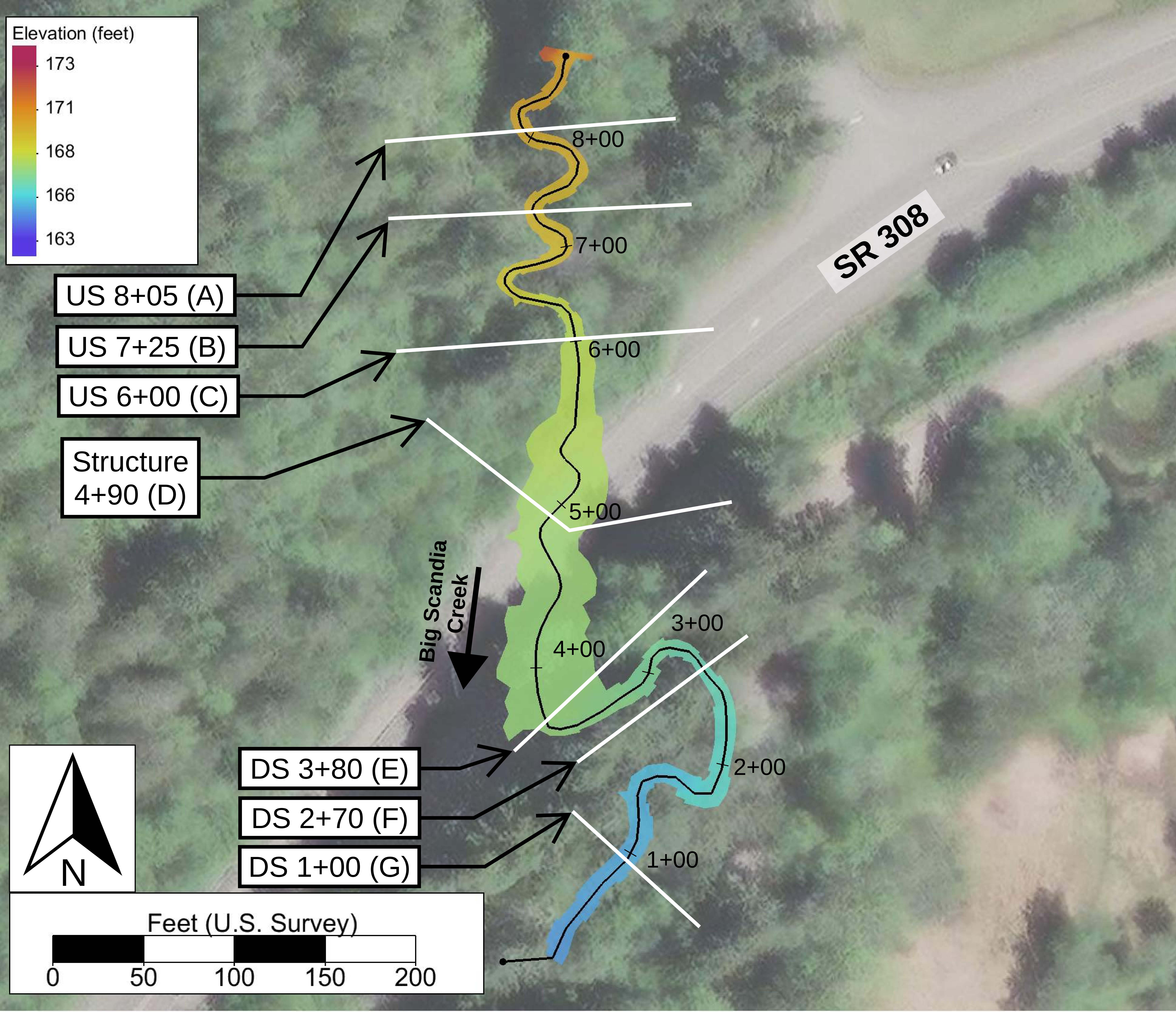


Figure H.16: Natural conditions 2-year water surface elevation

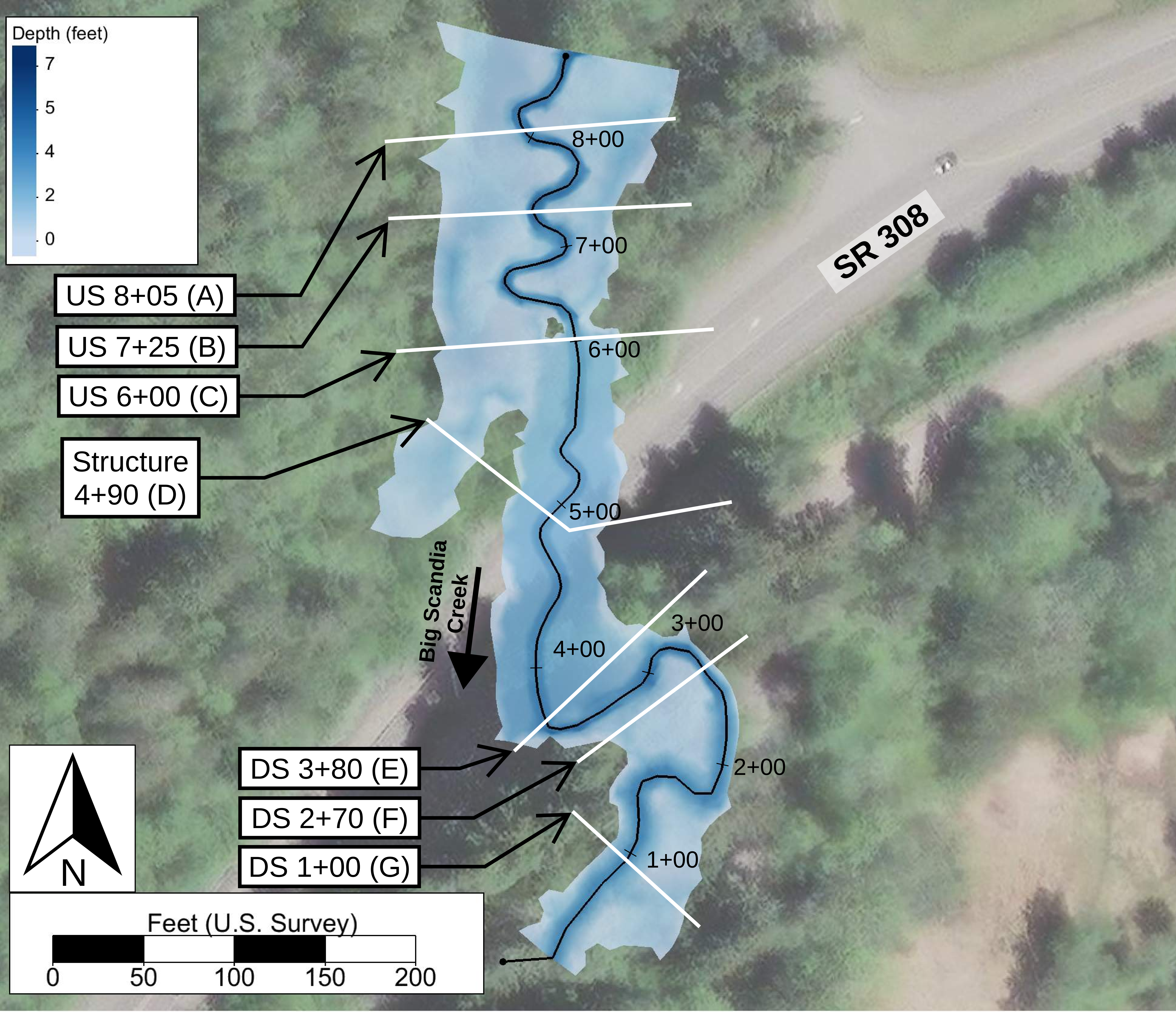


Figure H.17: Natural conditions 100-year depth

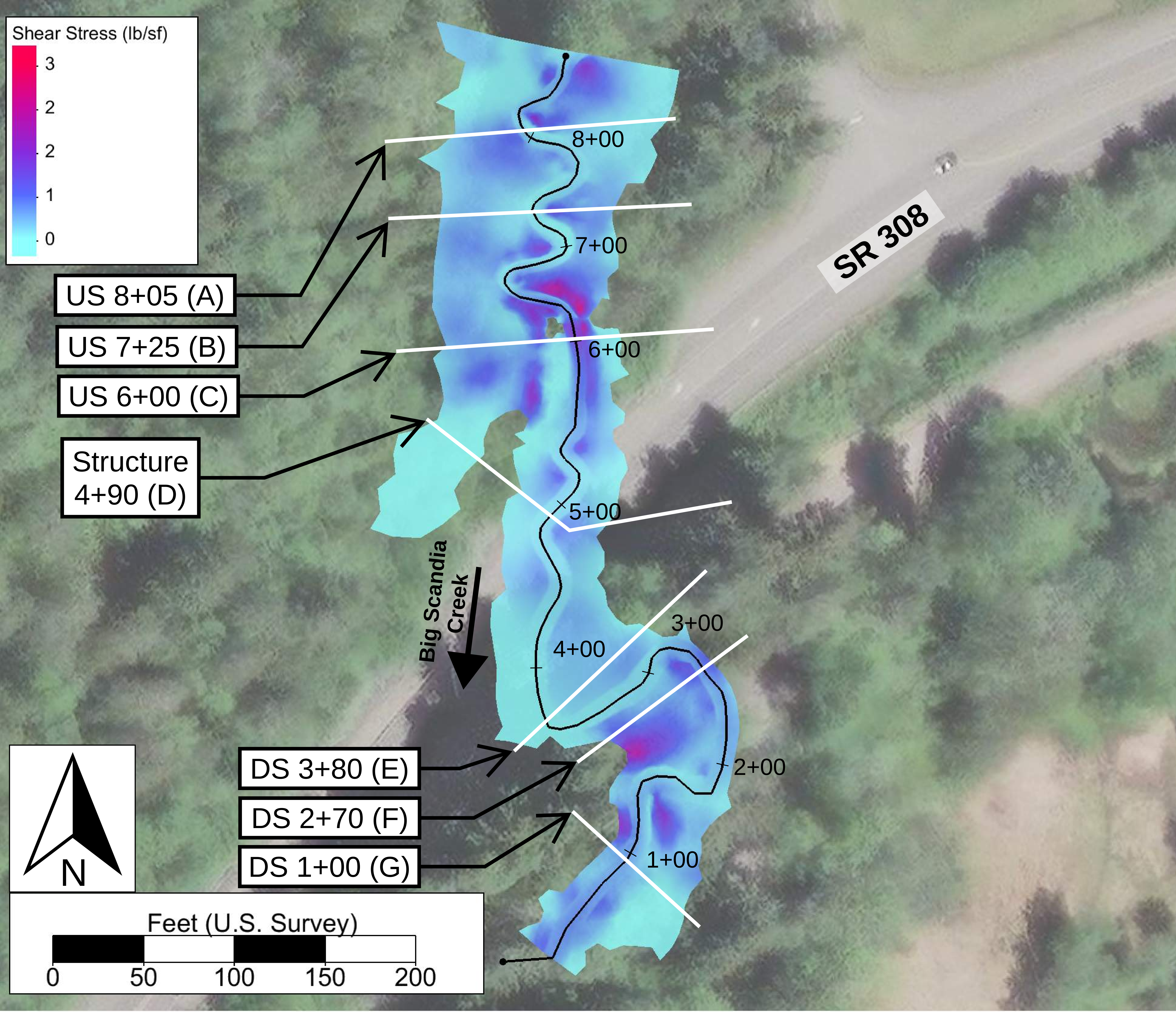


Figure H.18: Natural conditions 100-year shear stress

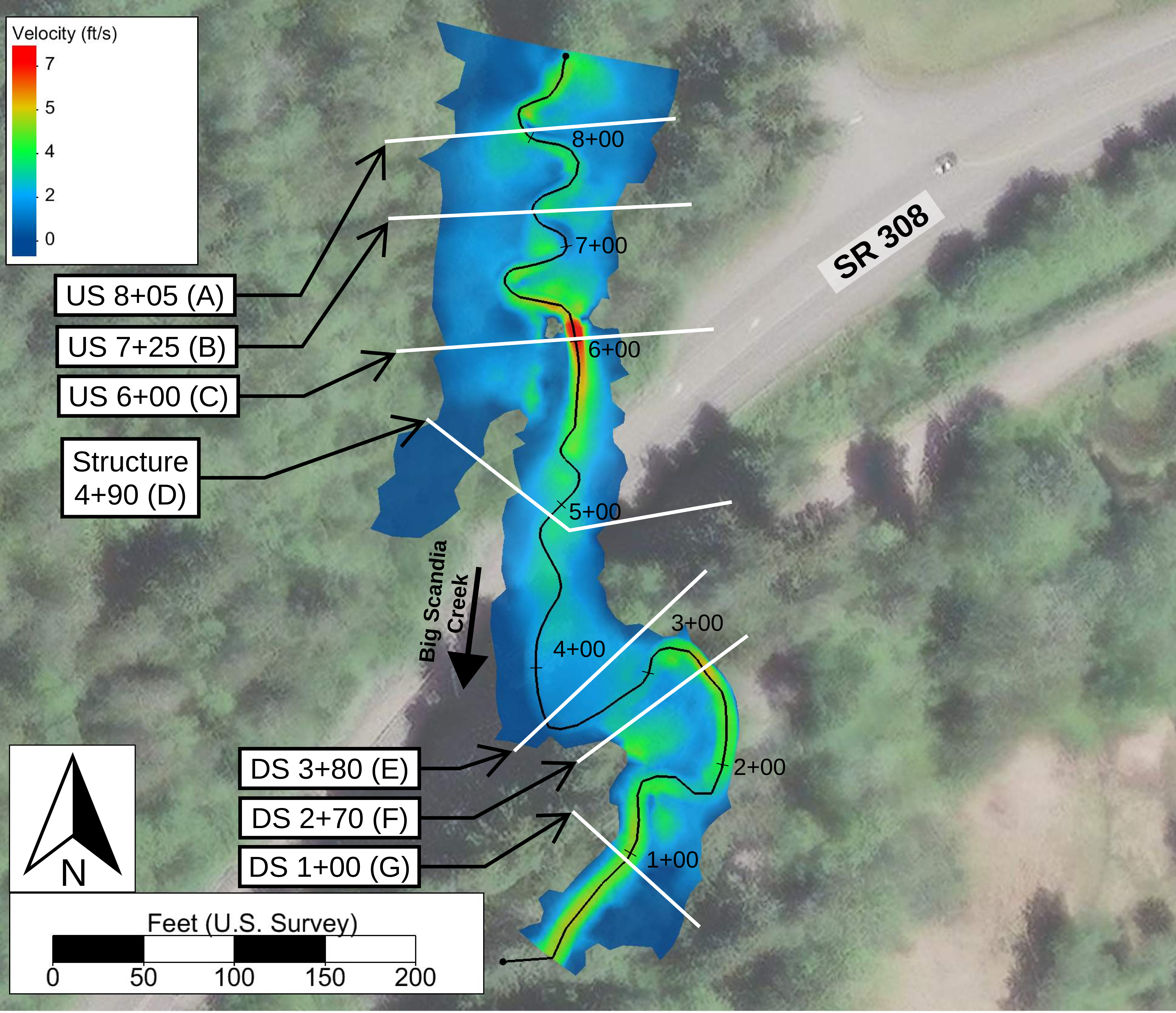


Figure H.19: Natural conditions 100-year velocity

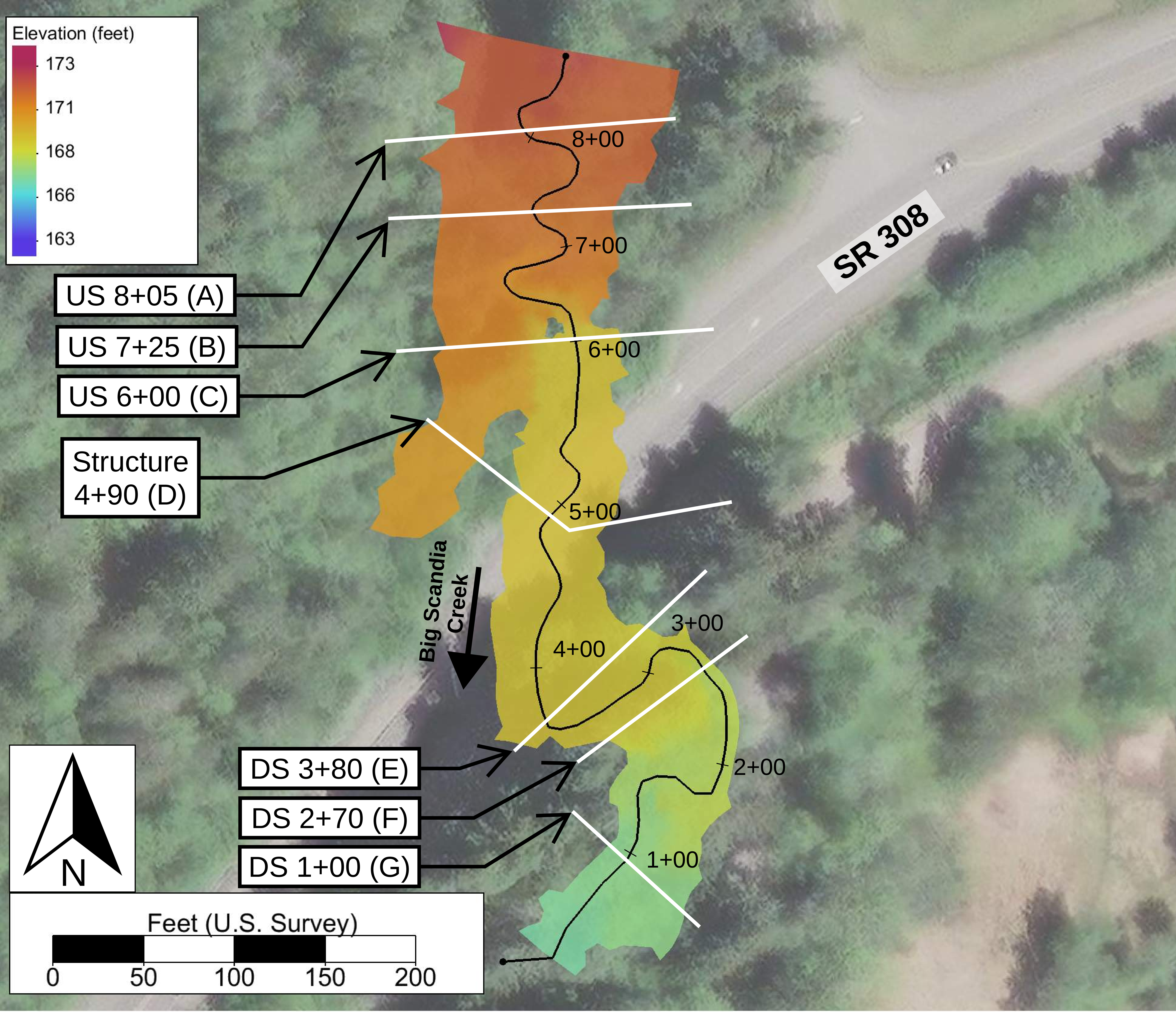


Figure H.20: Natural conditions 100-year water surface elevation

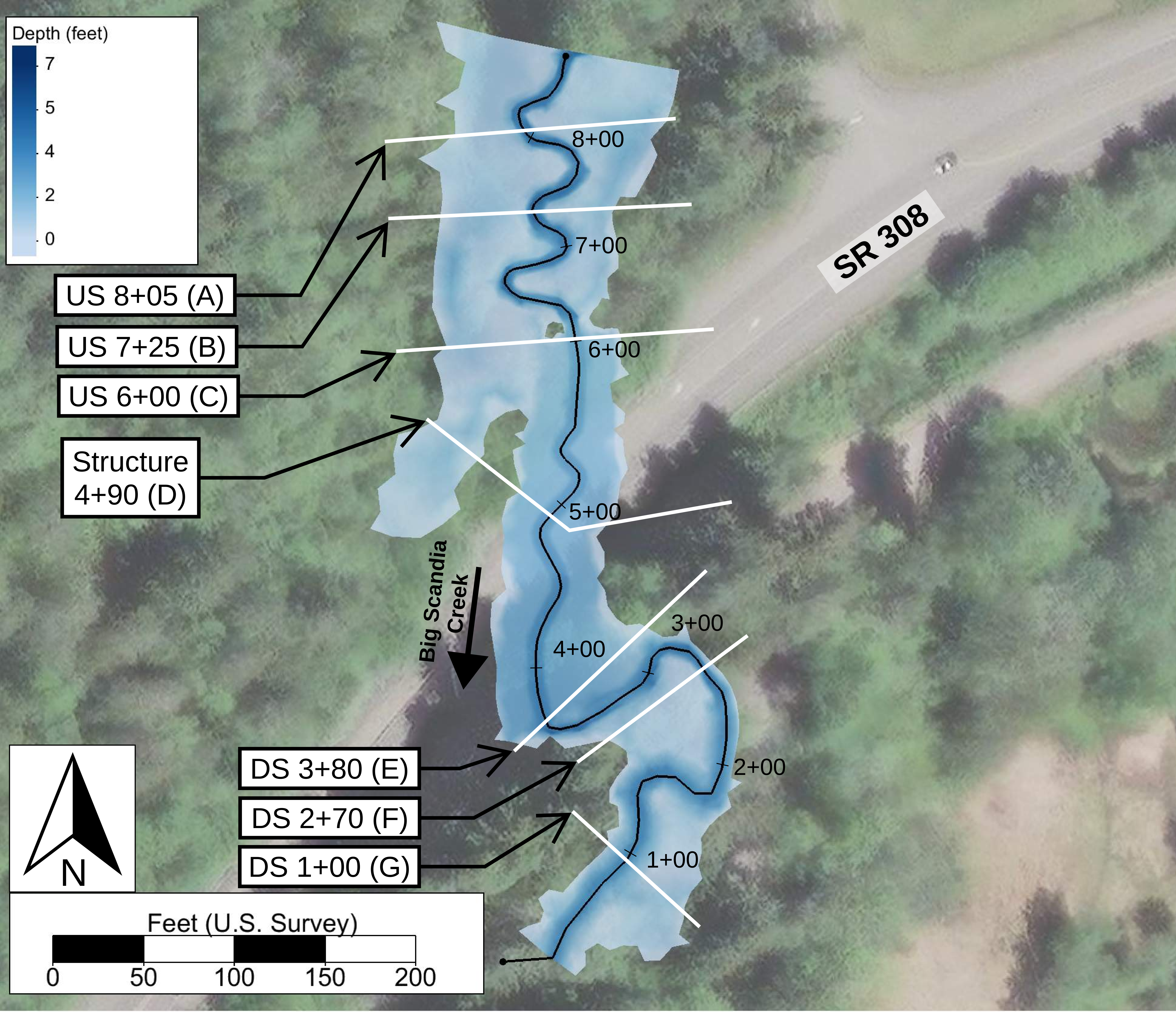


Figure H.21: Natural conditions 500-year depth

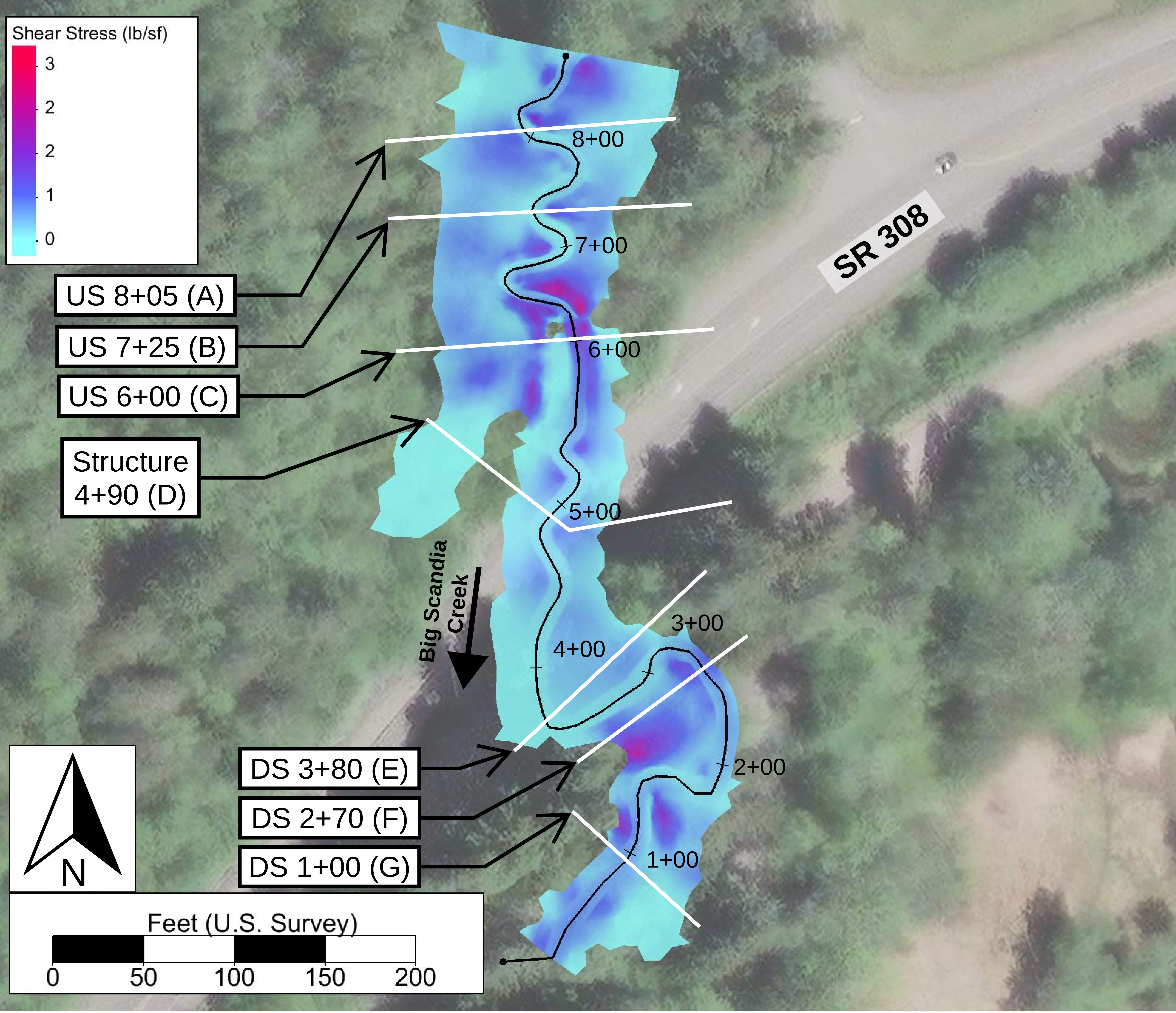


Figure H.22: Natural conditions 500-year shear stress

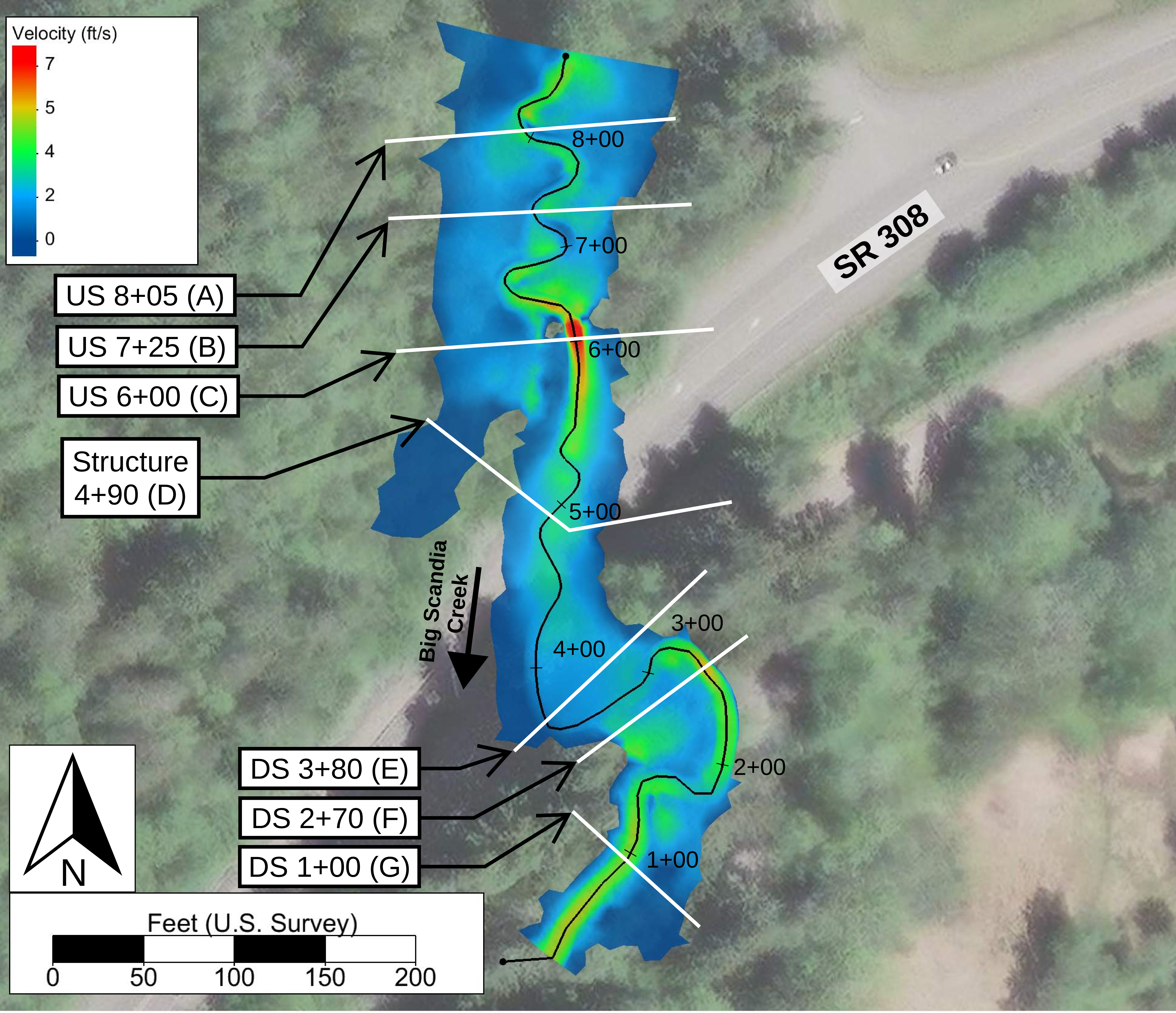


Figure H.23: Natural conditions 500-year velocity

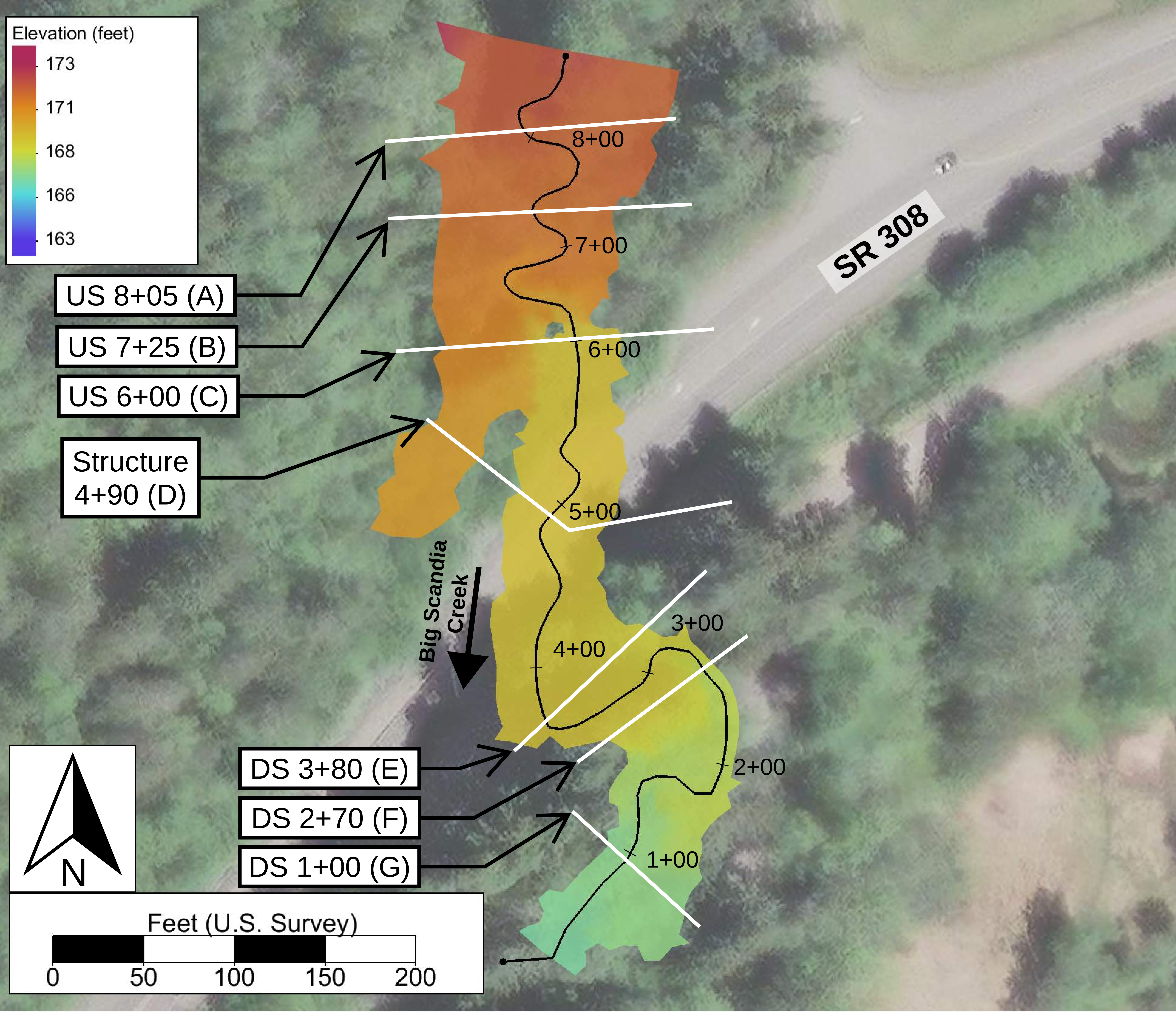


Figure H.24: Natural conditions 500-year water surface elevation

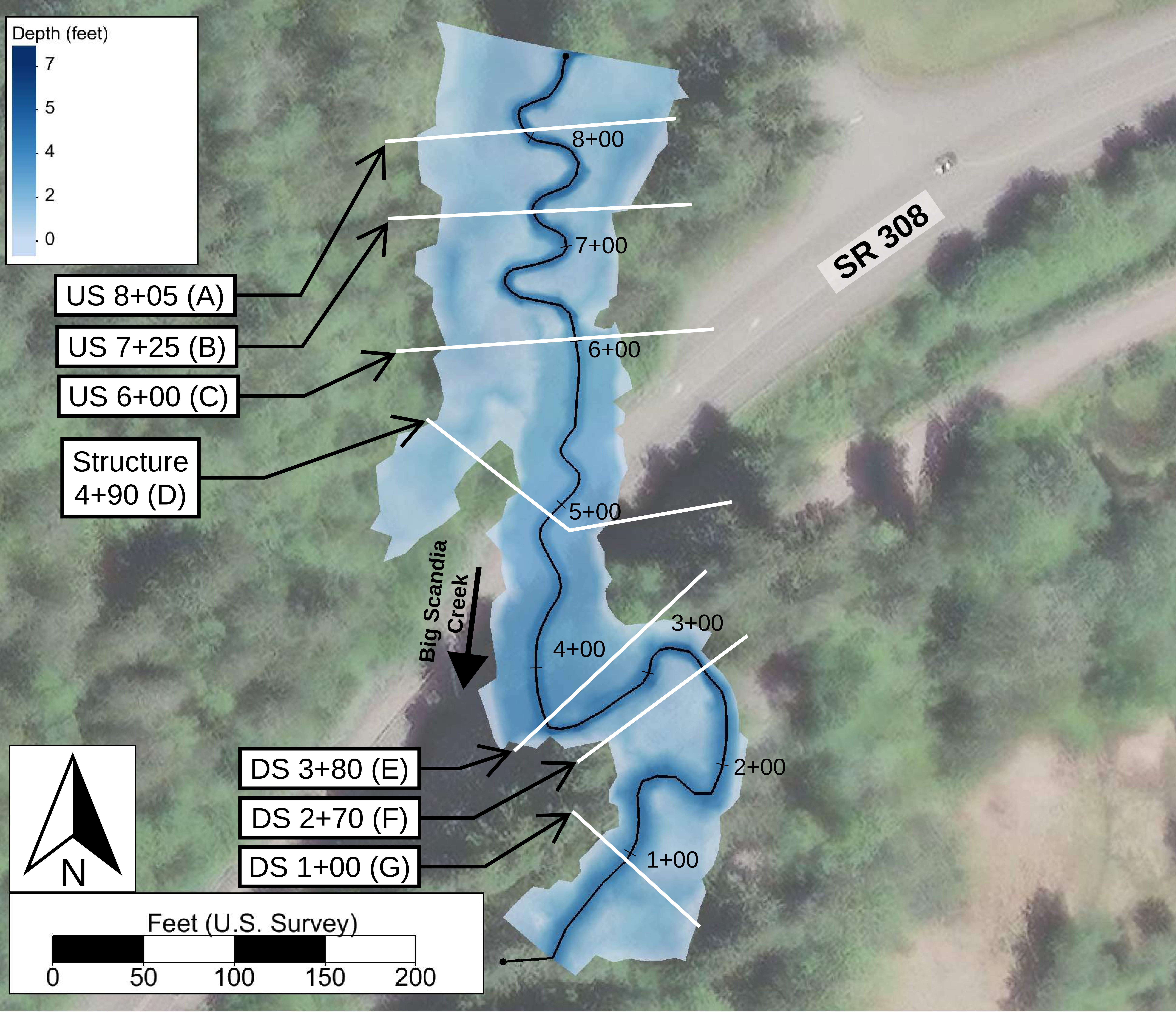


Figure H.25: Natural conditions 2080 100-year depth

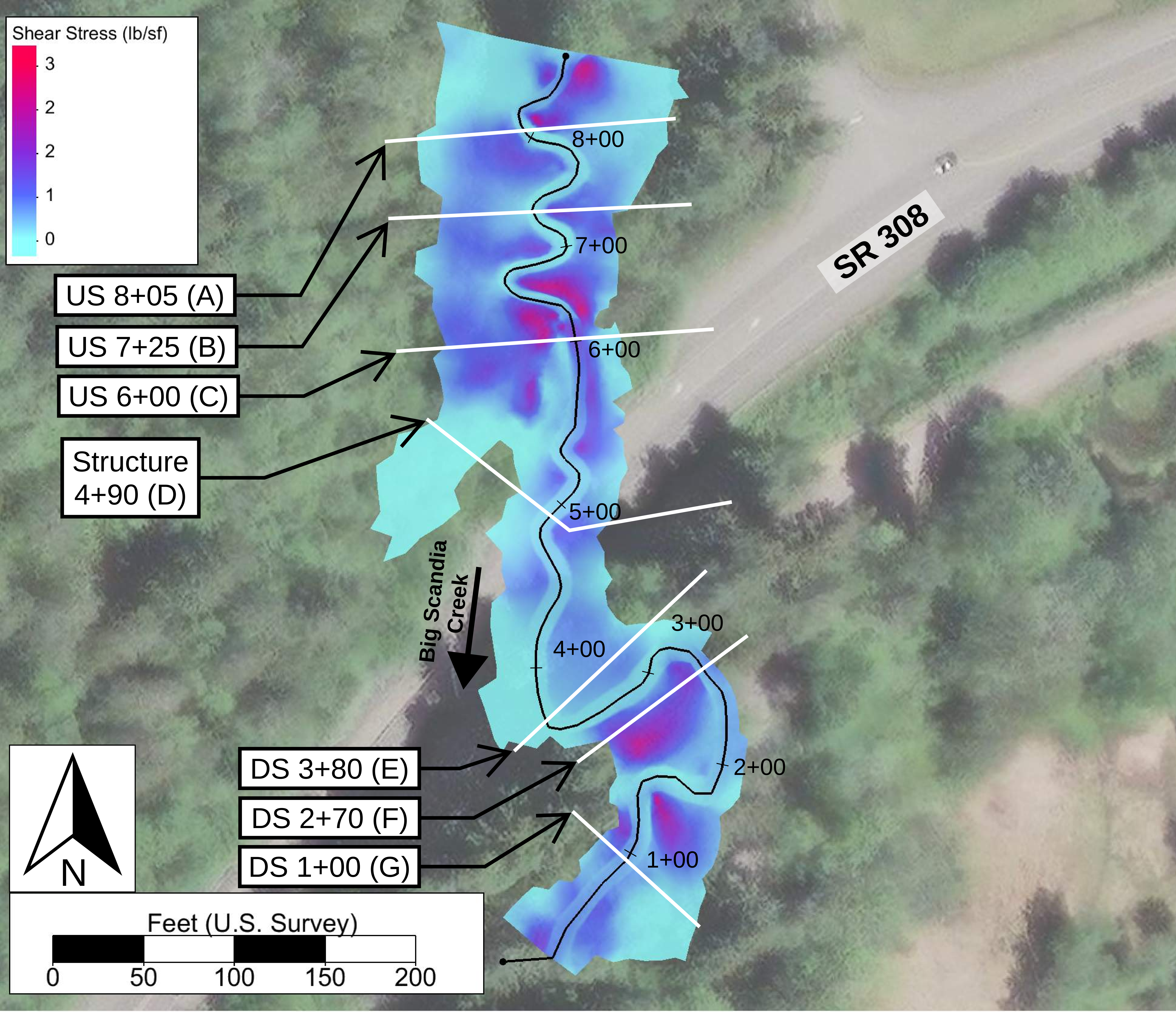


Figure H.26: Natural conditions 2080 100-year shear stress

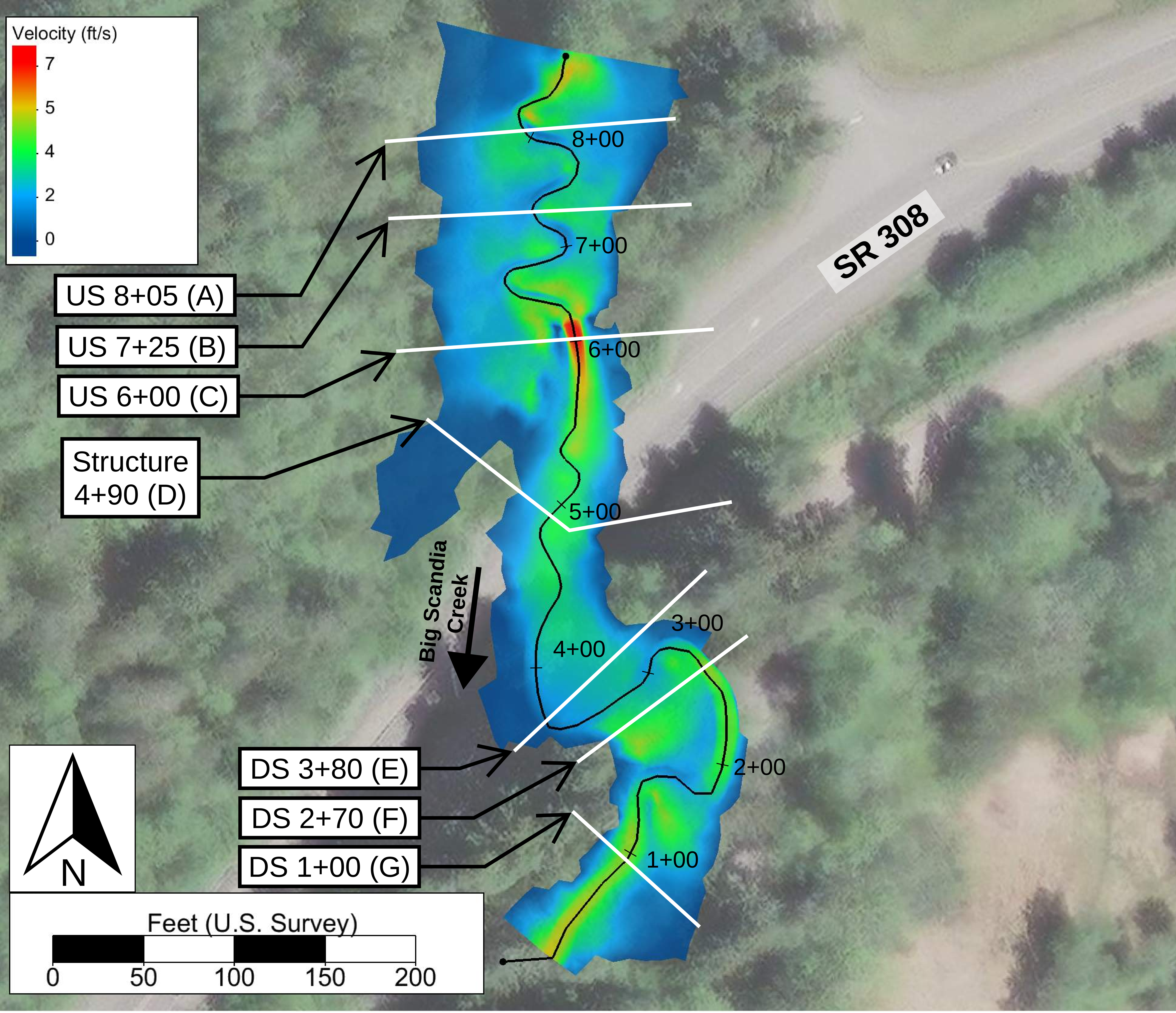


Figure H.27: Natural conditions 2080 100-year velocity

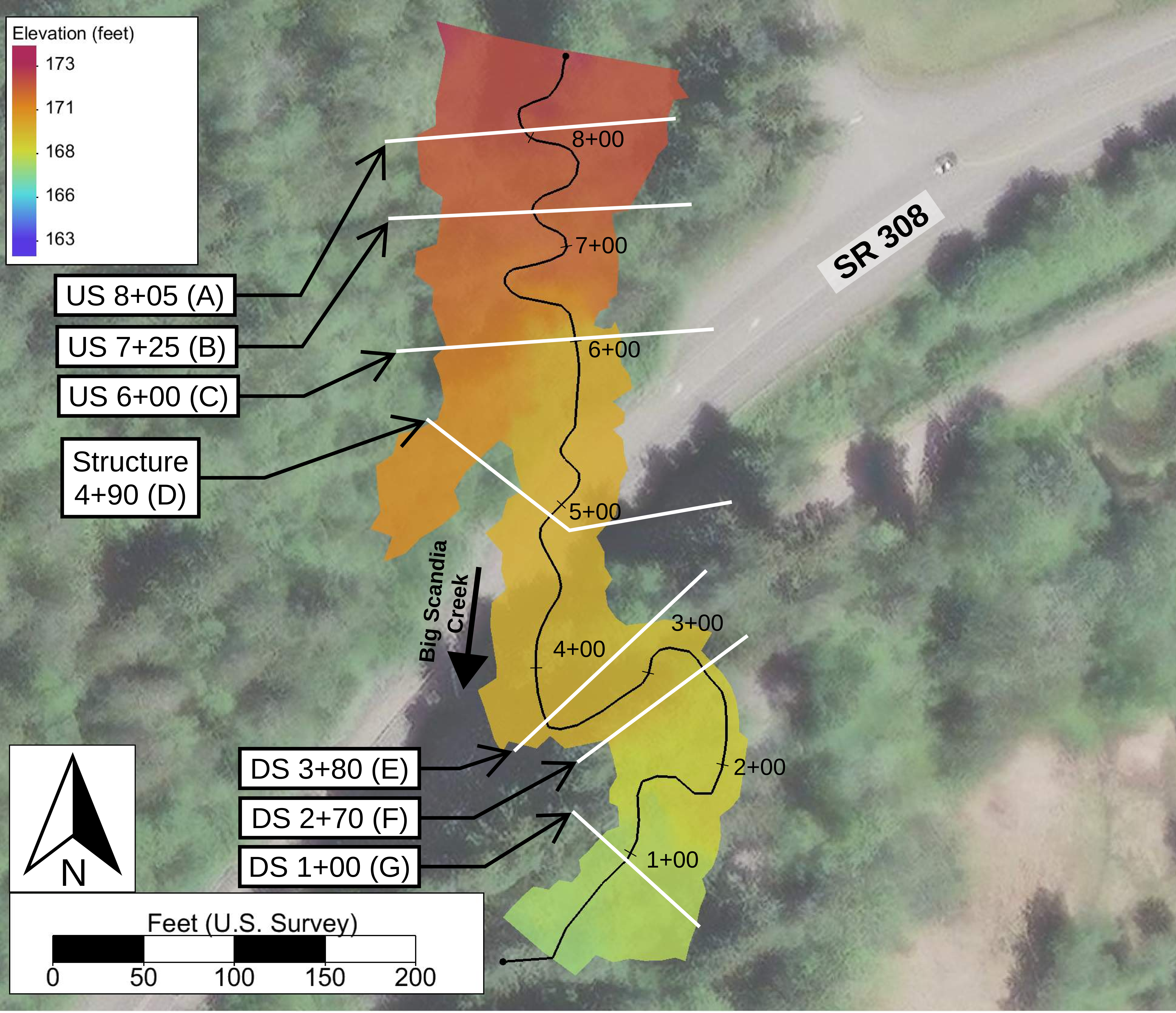


Figure H.28: Natural conditions 2080 100-year water surface elevation

Proposed Conditions SRH-2D Results

Planview

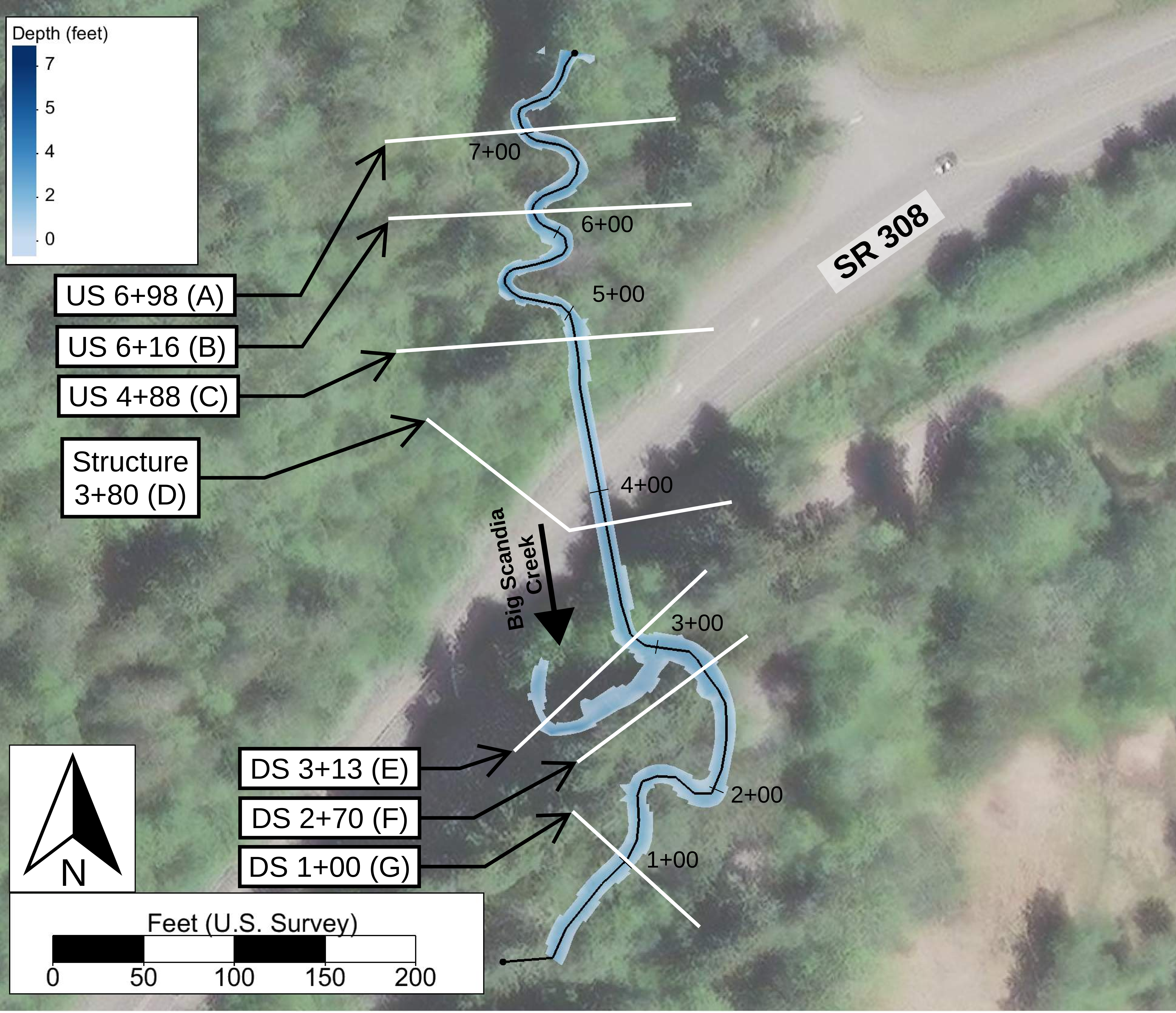


Figure H.29: Proposed conditions 2-year depth

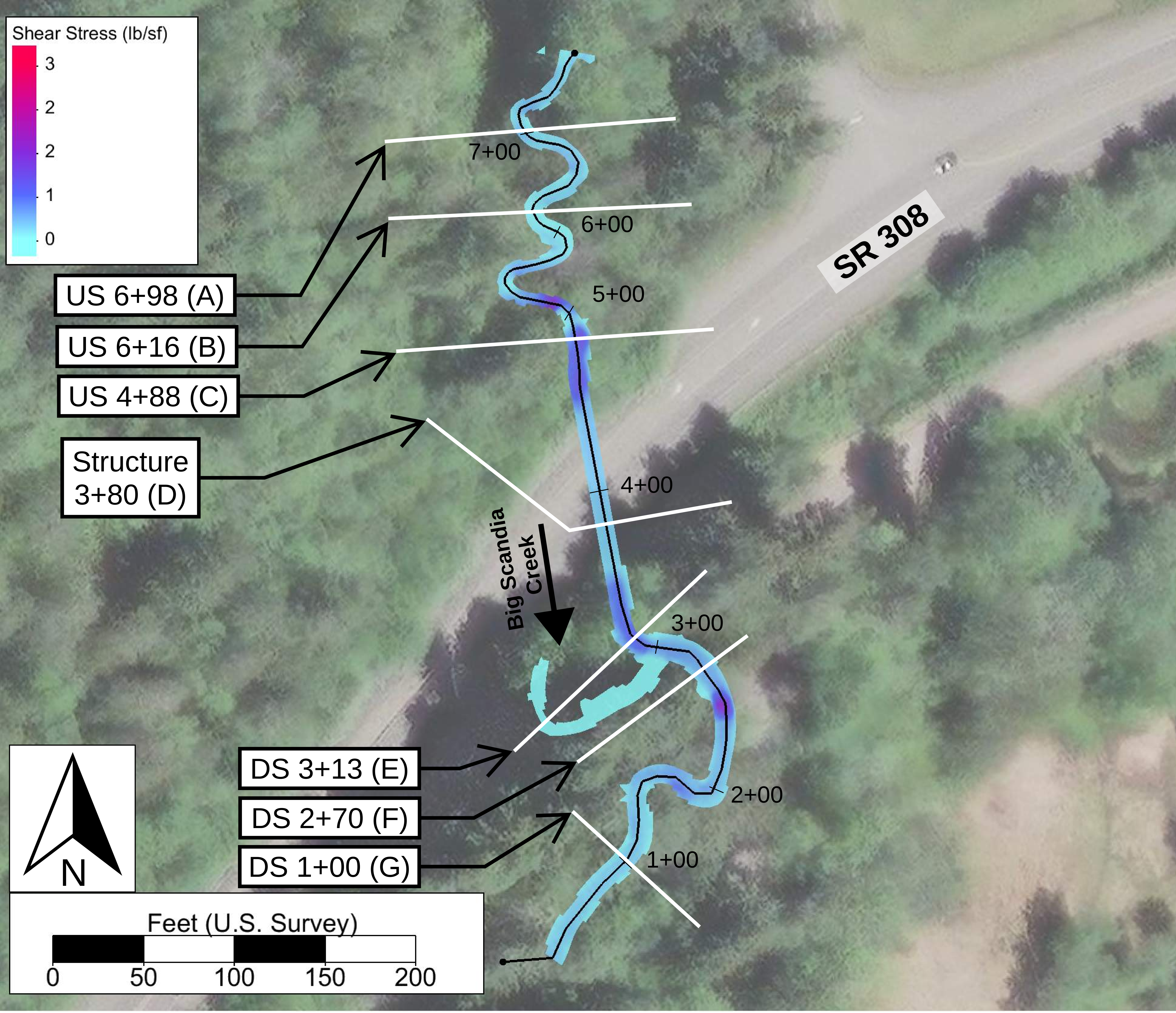


Figure H.30: Proposed conditions 2-year shear stress

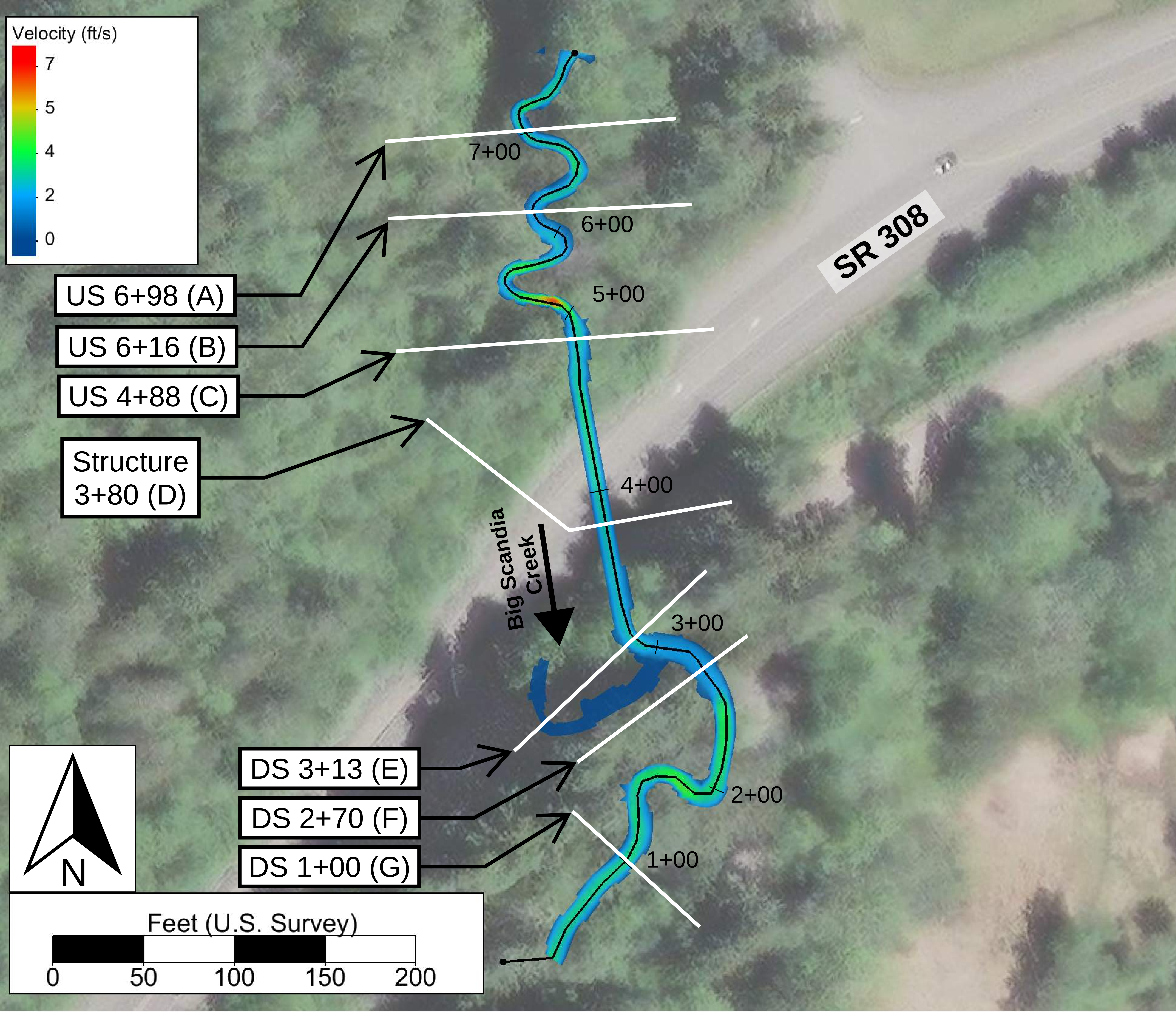


Figure H.31: Proposed conditions 2-year velocity

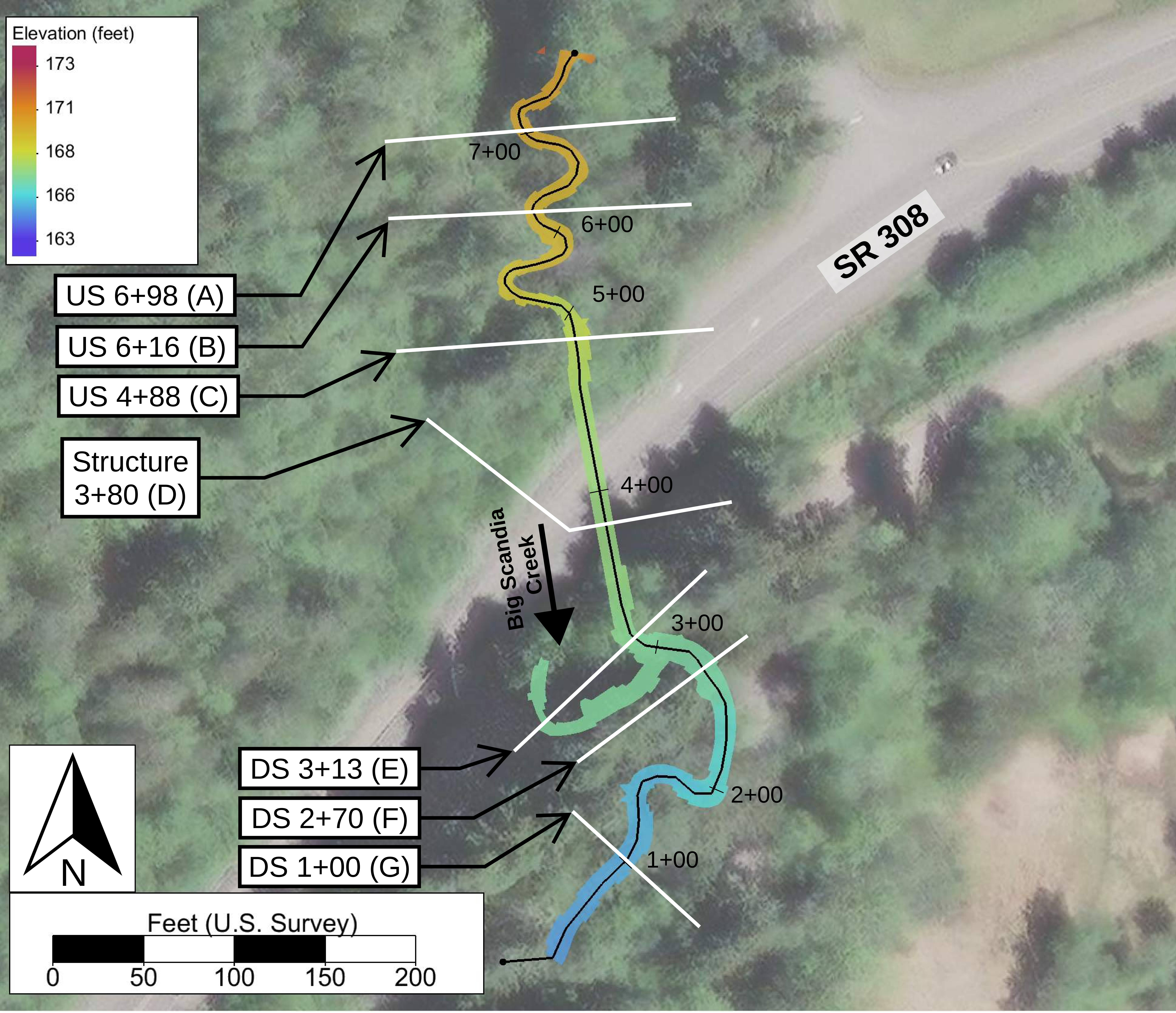


Figure H.32: Proposed conditions 2-year water surface elevation

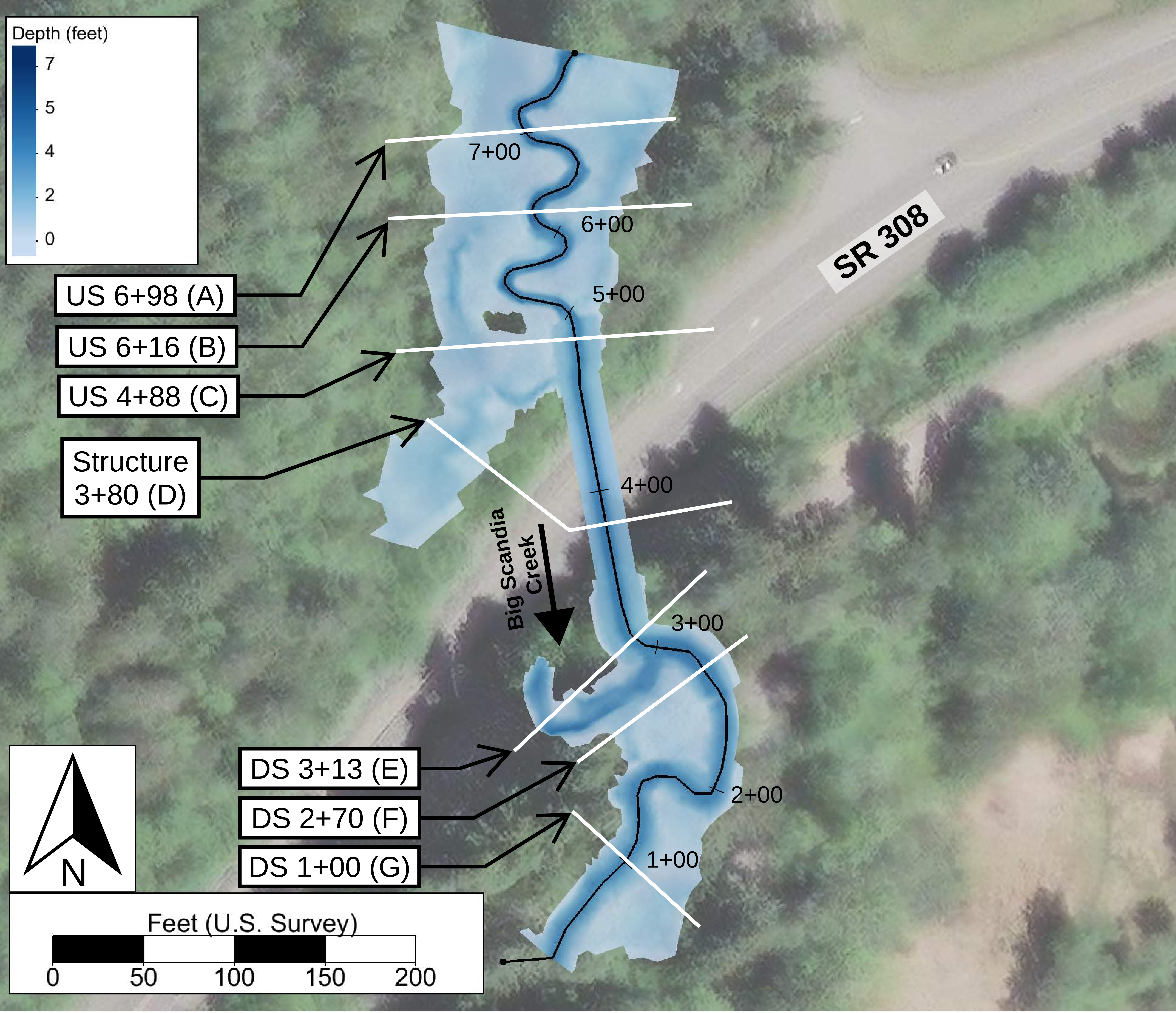


Figure H.33: Proposed conditions 100-year depth

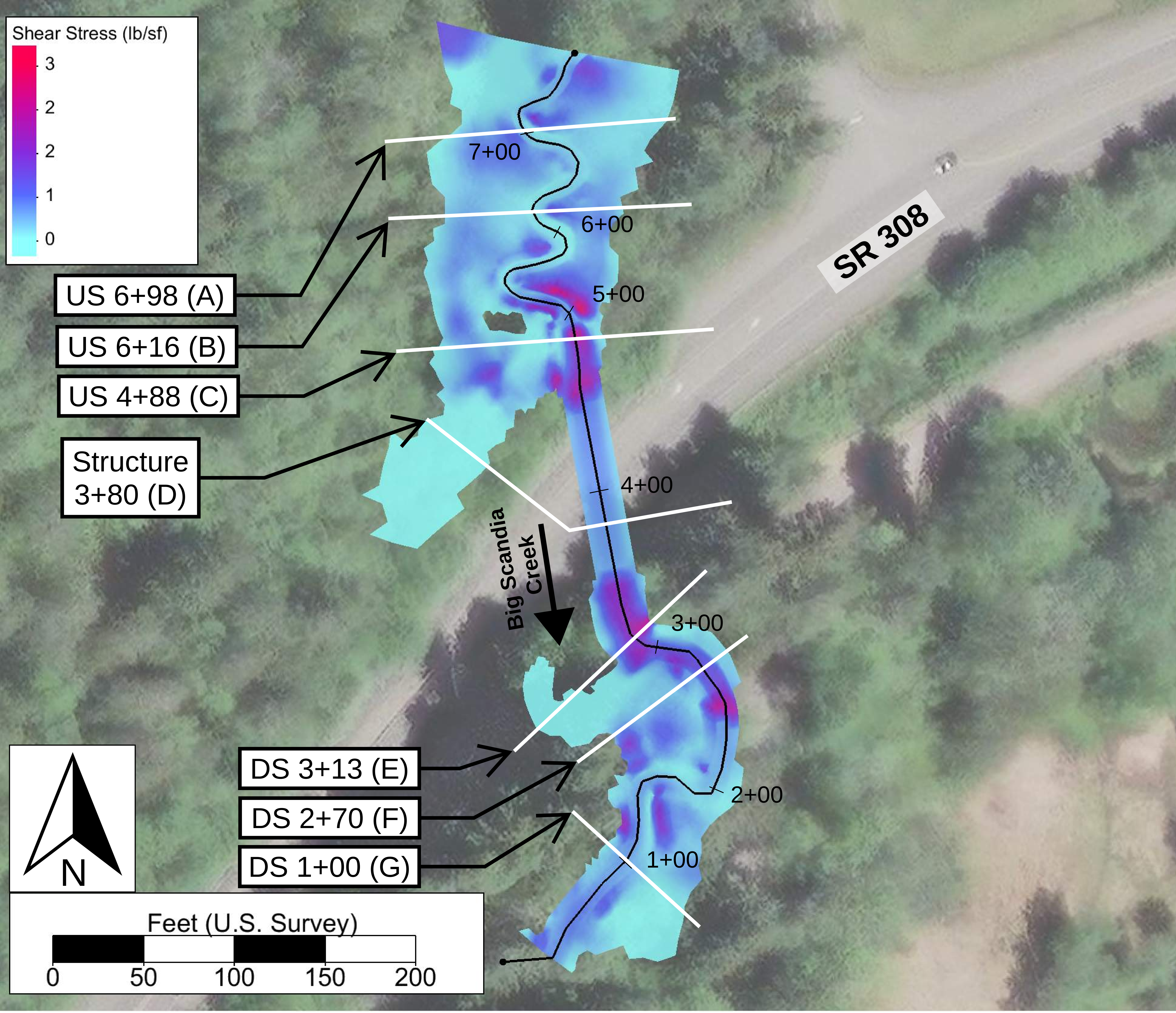


Figure H.34: Proposed conditions 100-year shear stress

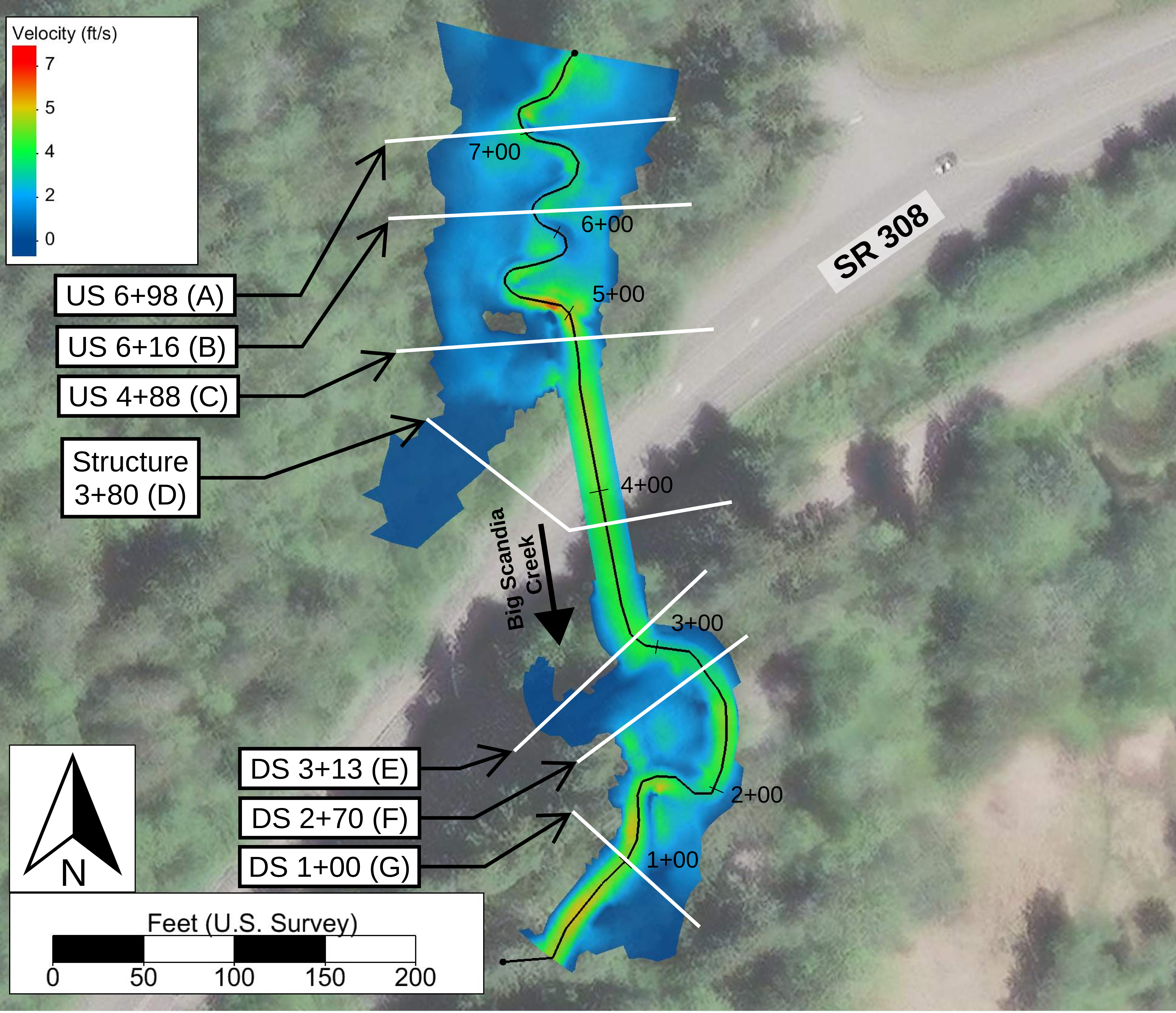


Figure H.35: Proposed conditions 100-year velocity

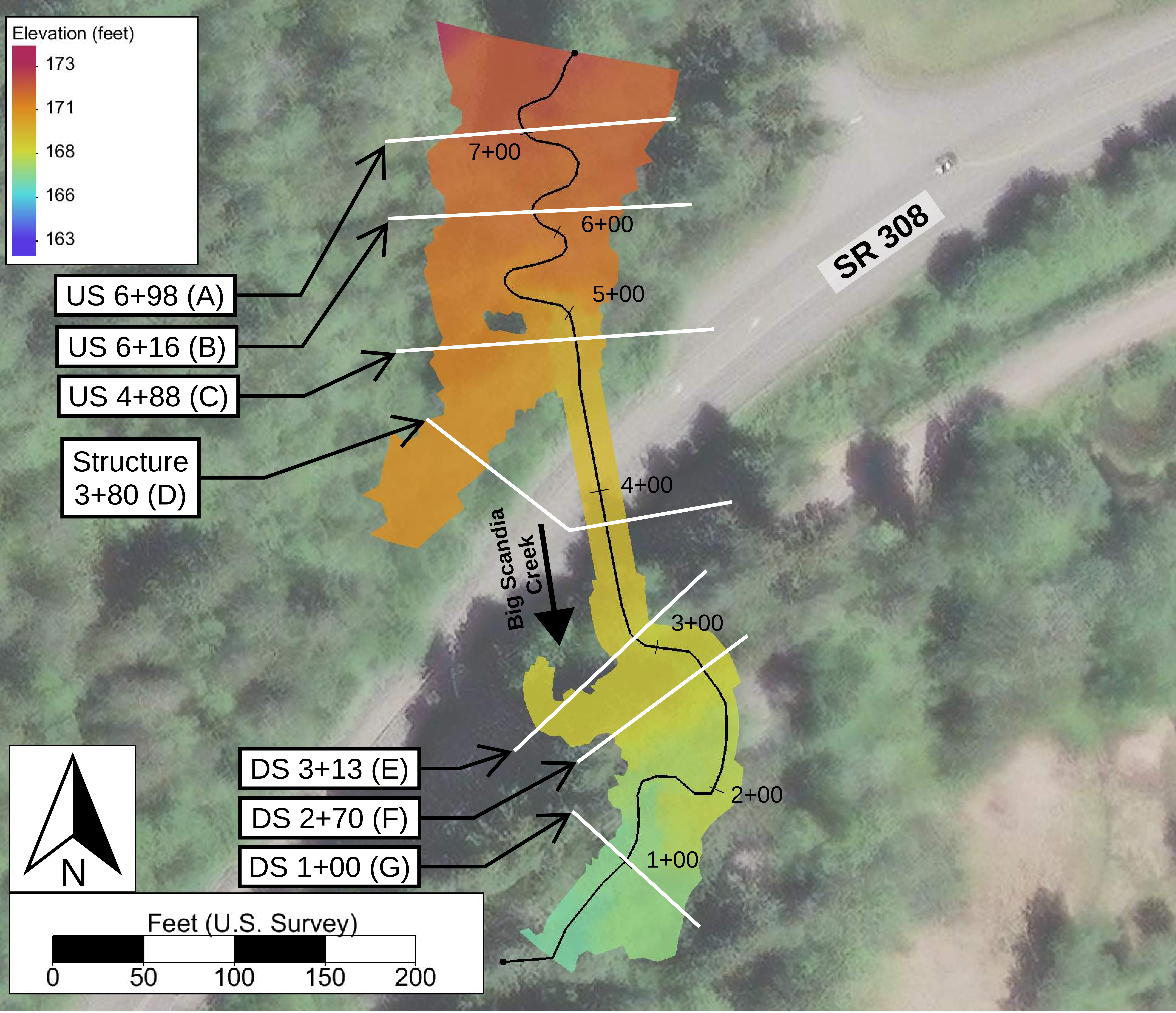


Figure H.36: Proposed conditions 100-year water surface elevation

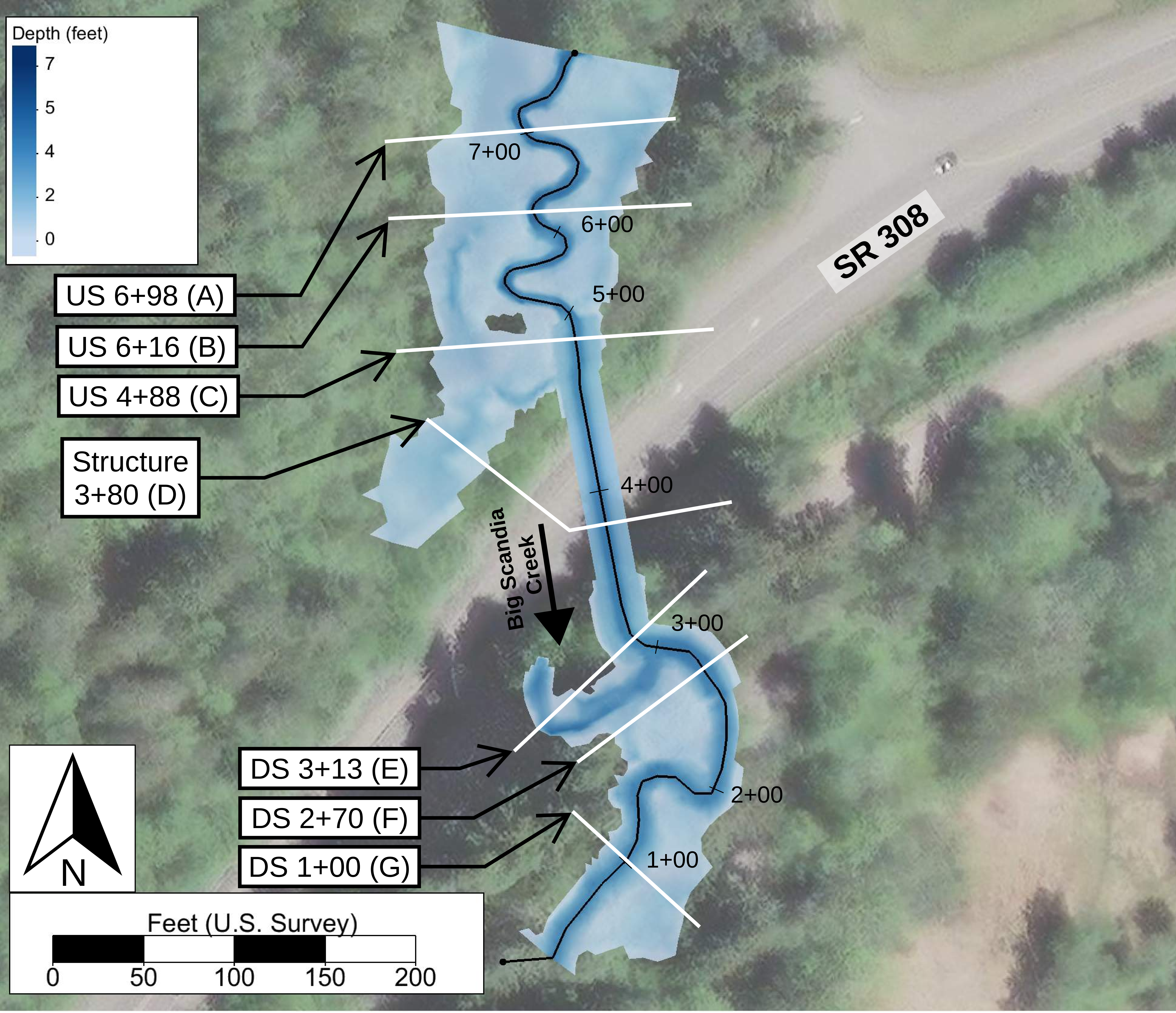


Figure H.37: Proposed conditions 500-year depth

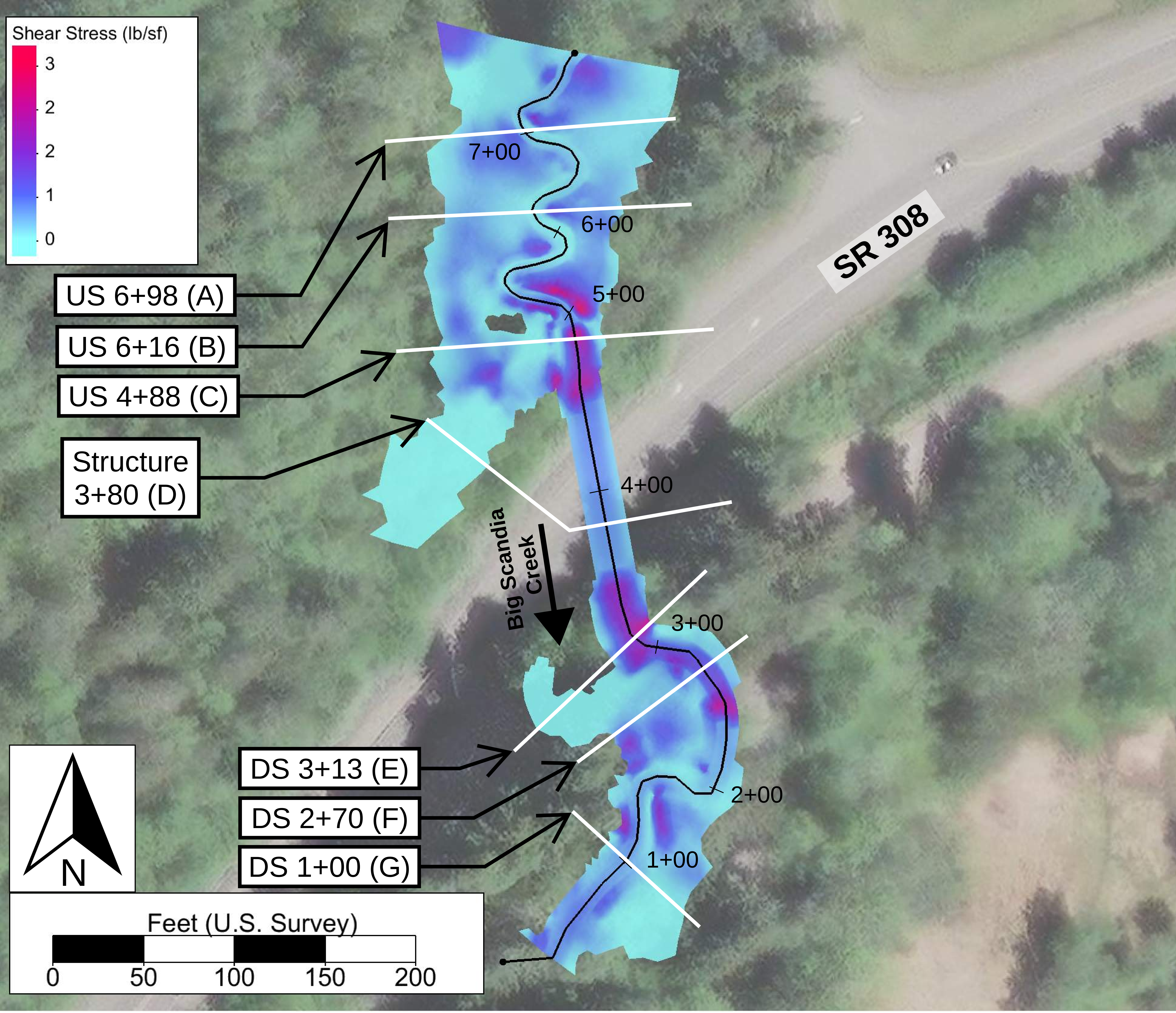


Figure H.38: Proposed conditions 500-year shear stress

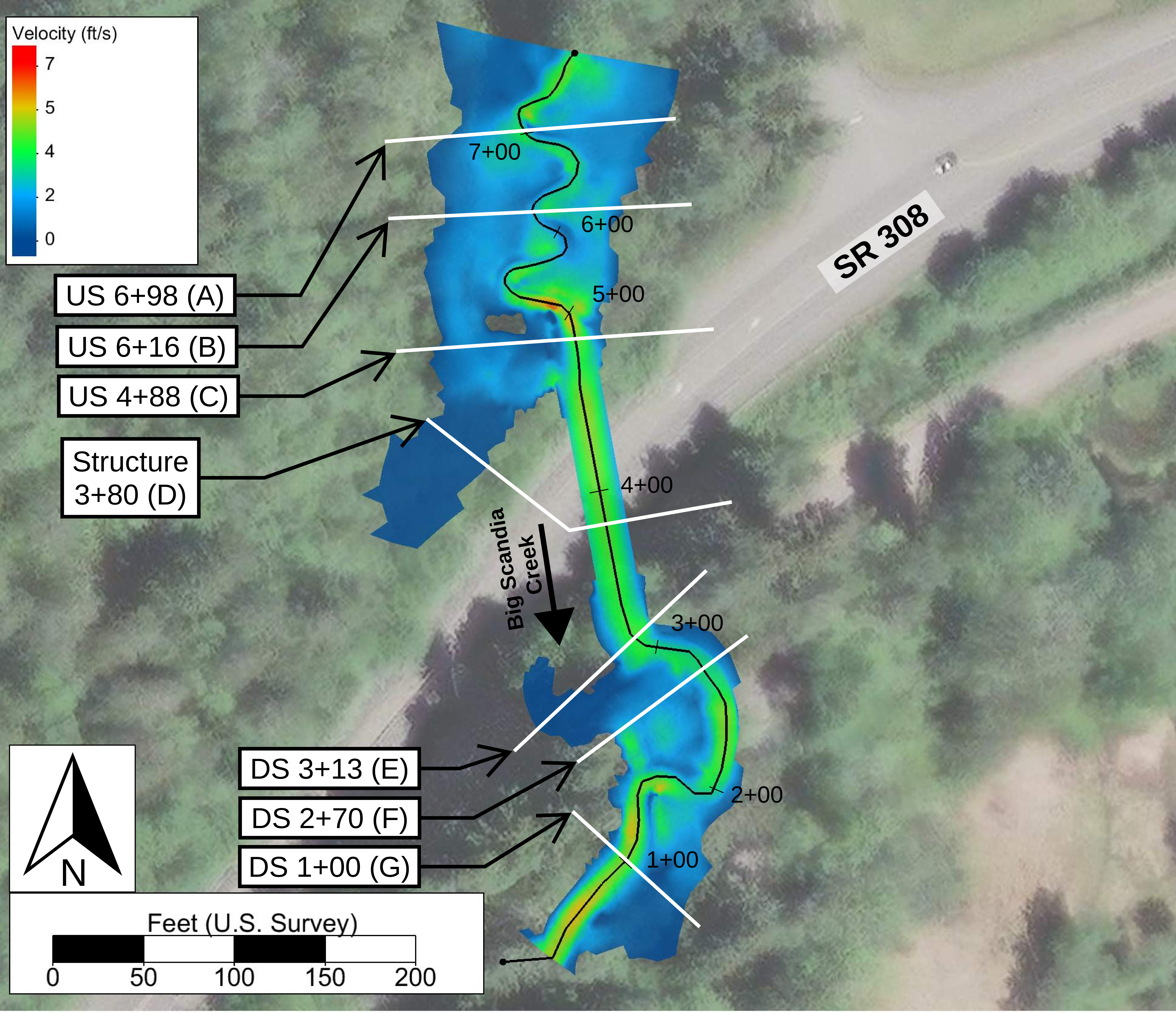


Figure H.39: Proposed conditions 500-year velocity

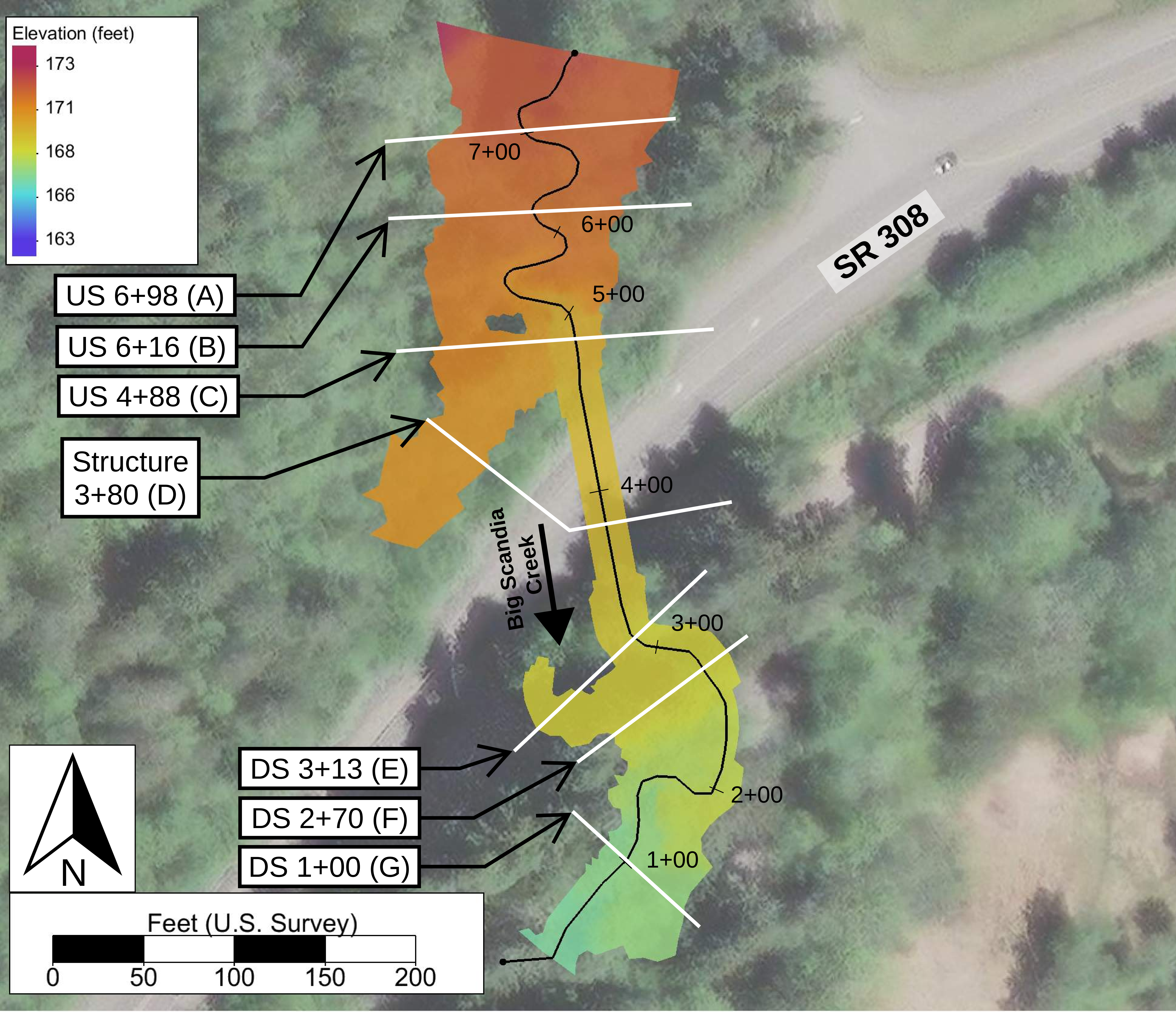


Figure H.40: Proposed conditions 500-year water surface elevation

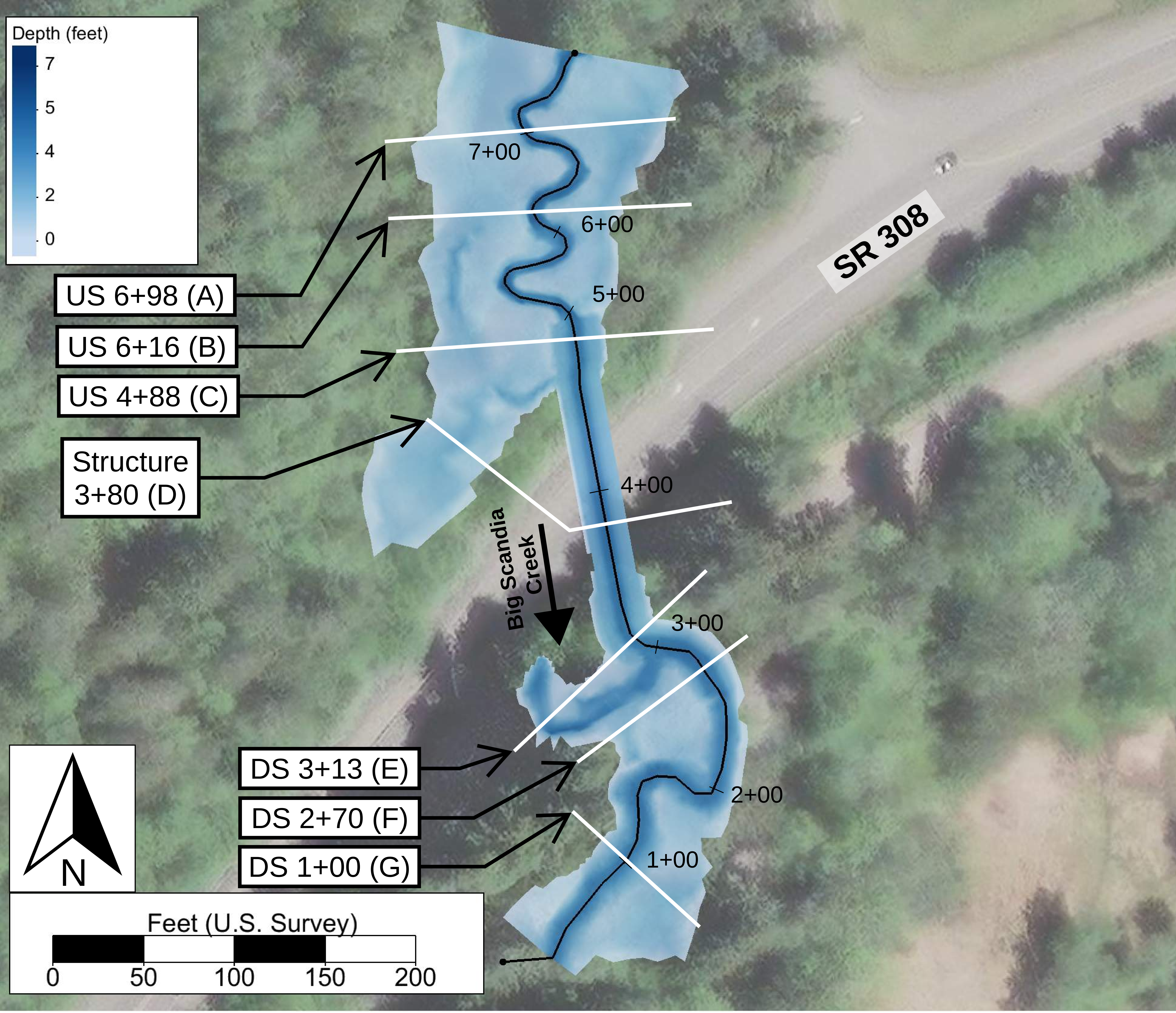


Figure H.41: Proposed conditions 2080 100-year depth

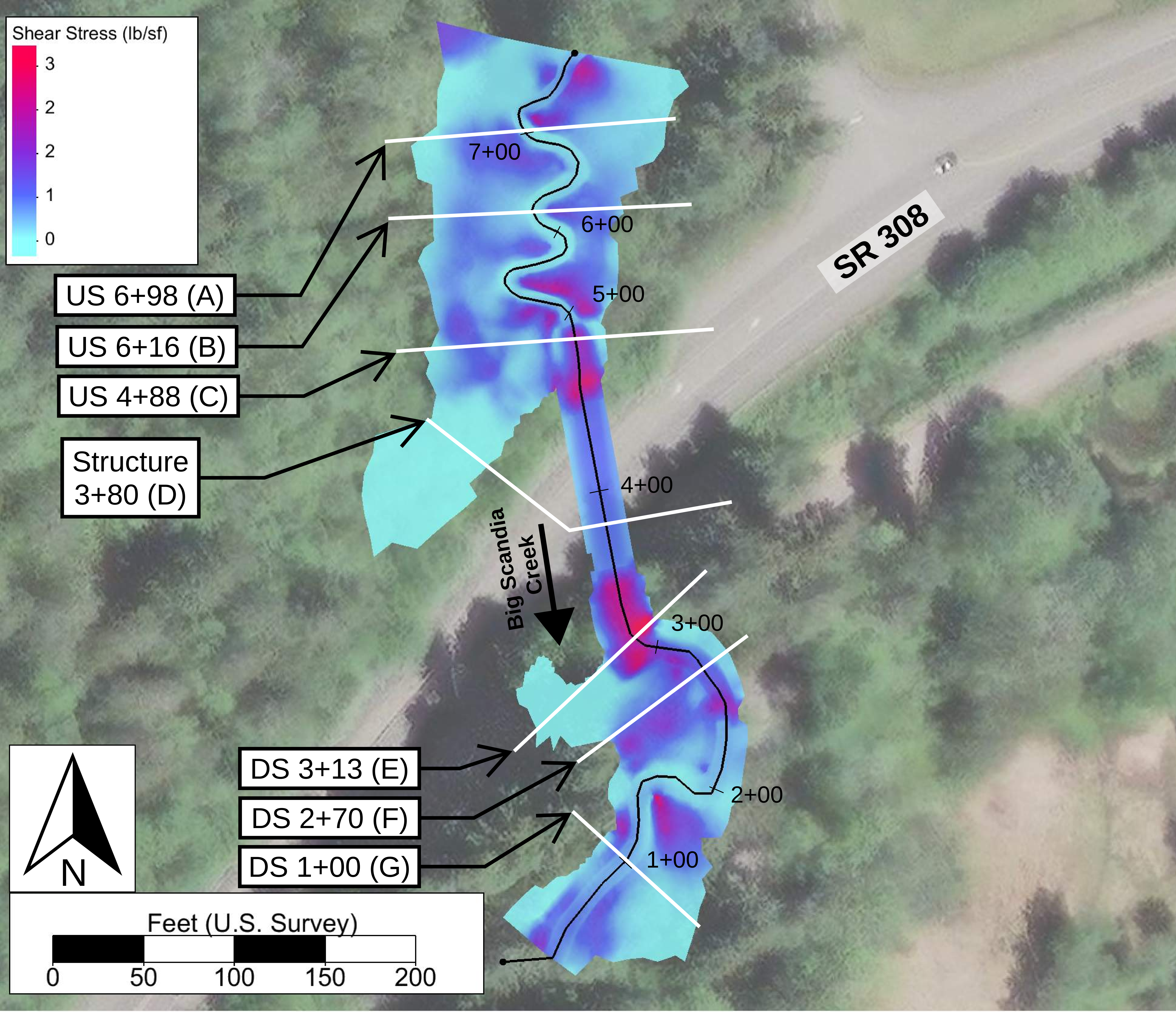


Figure H.42: Proposed conditions 2080 100-year shear stress

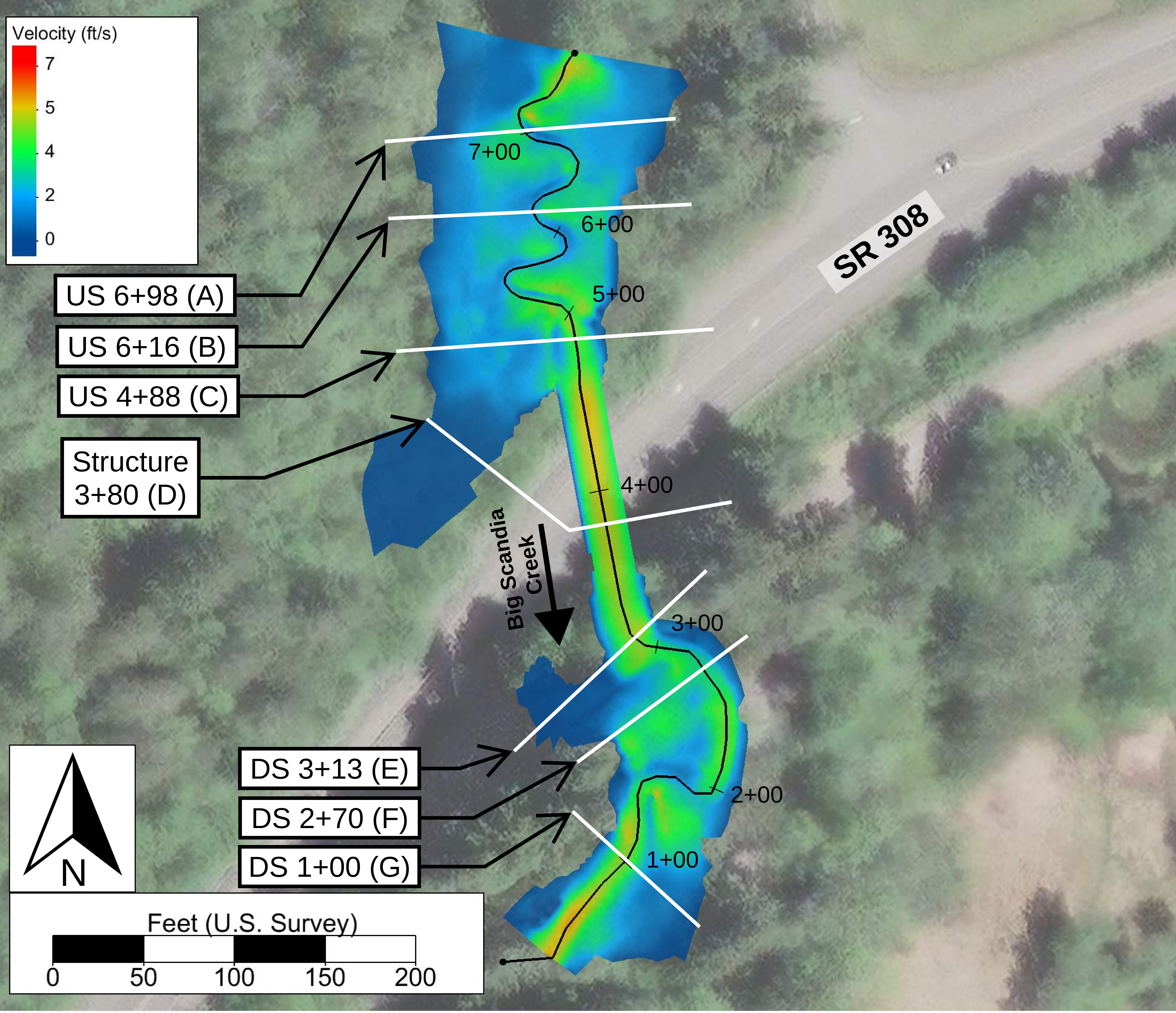


Figure H.43: Proposed conditions 2080 100-year velocity

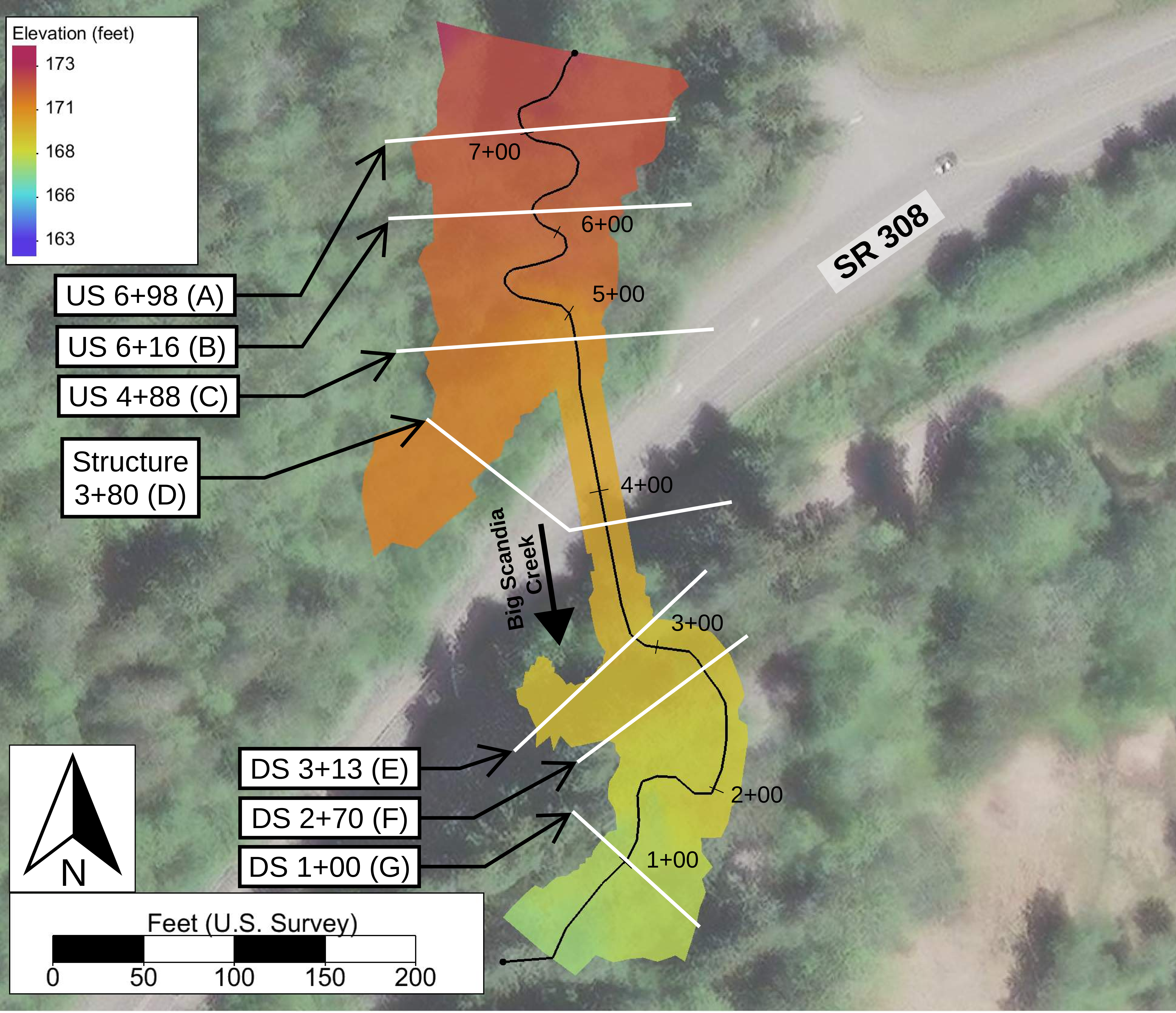


Figure H.44: Proposed conditions 2080 100-year water surface elevation

Existing Conditions SRH-2D Results

Cross Sections

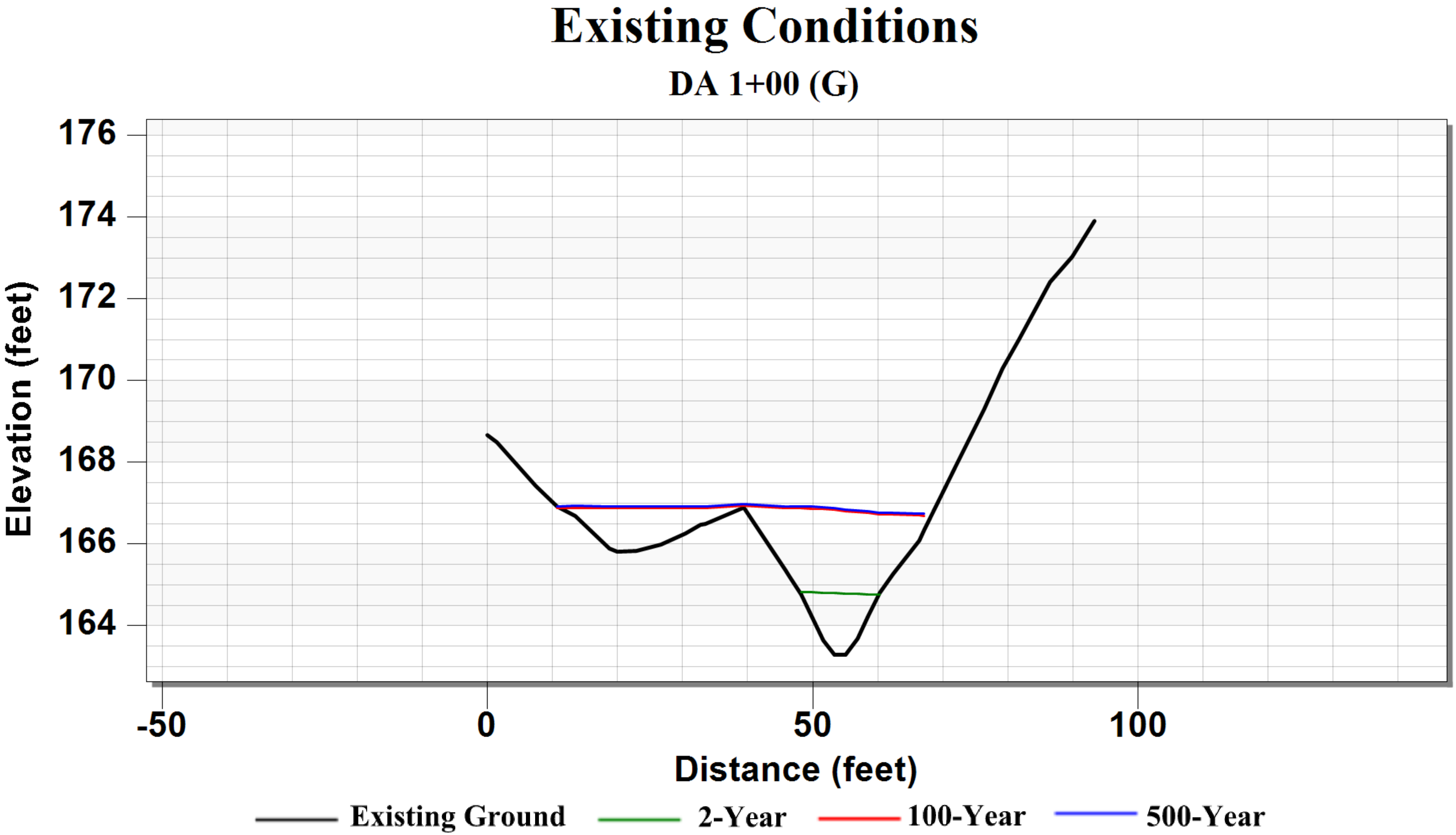


Figure H.45: Existing conditions water surface elevation STA 1+00

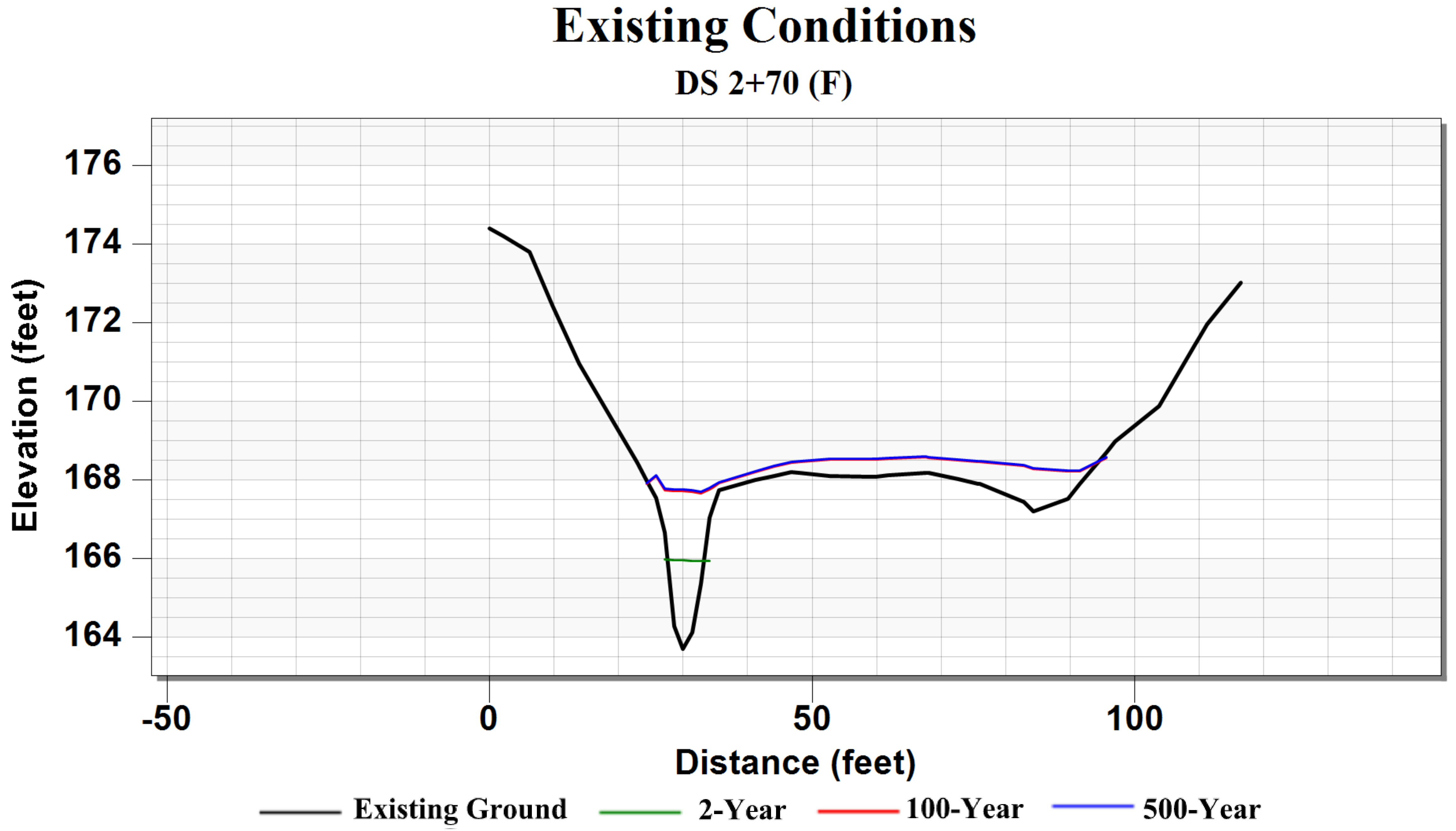


Figure H.46: Existing conditions water surface elevation STA 2+70

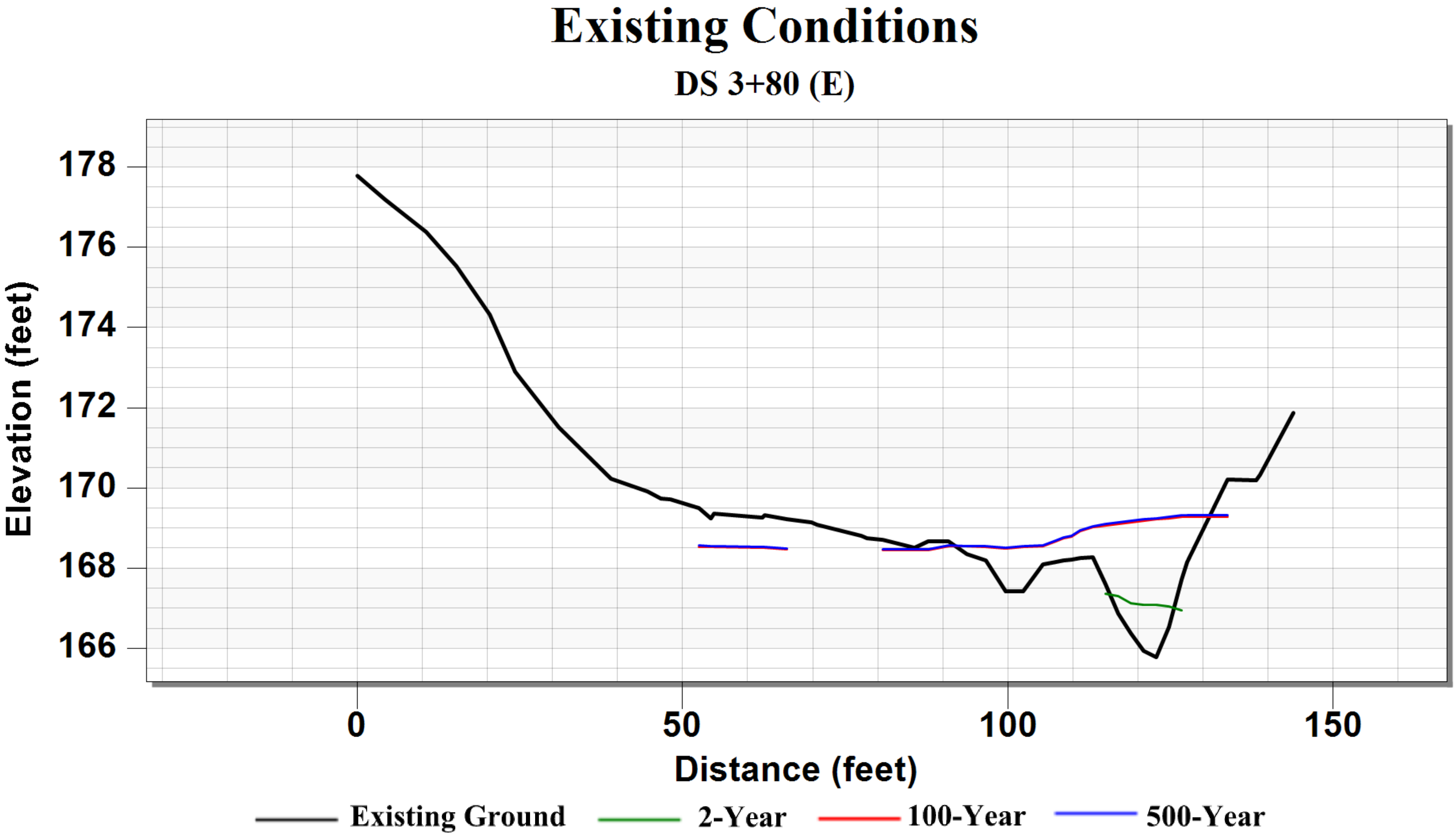


Figure H.47: Existing conditions water surface elevation STA 3+80

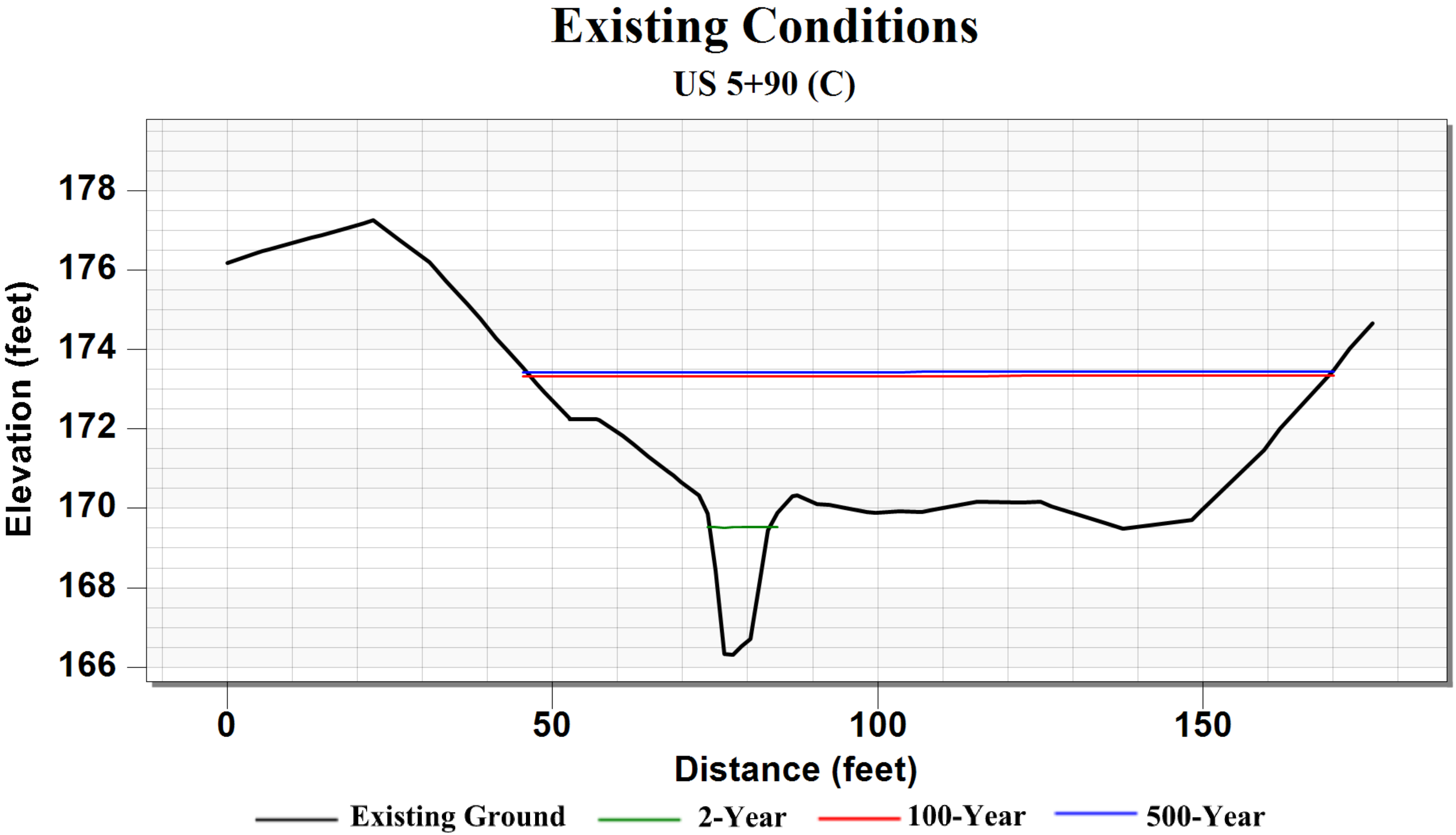


Figure H.48: Existing conditions water surface elevation STA 5+90

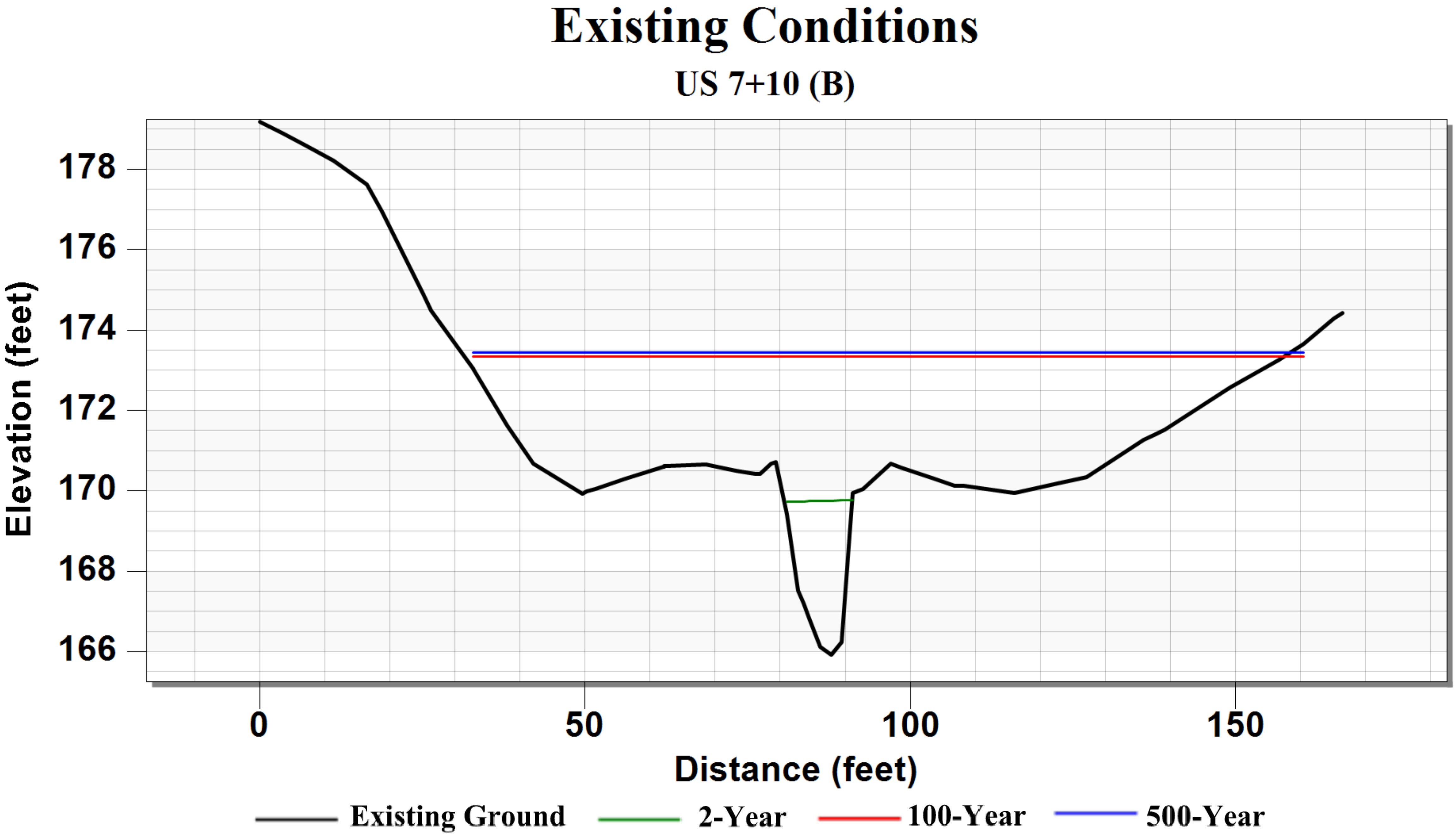


Figure H.49: Existing conditions water surface elevation STA 7+10

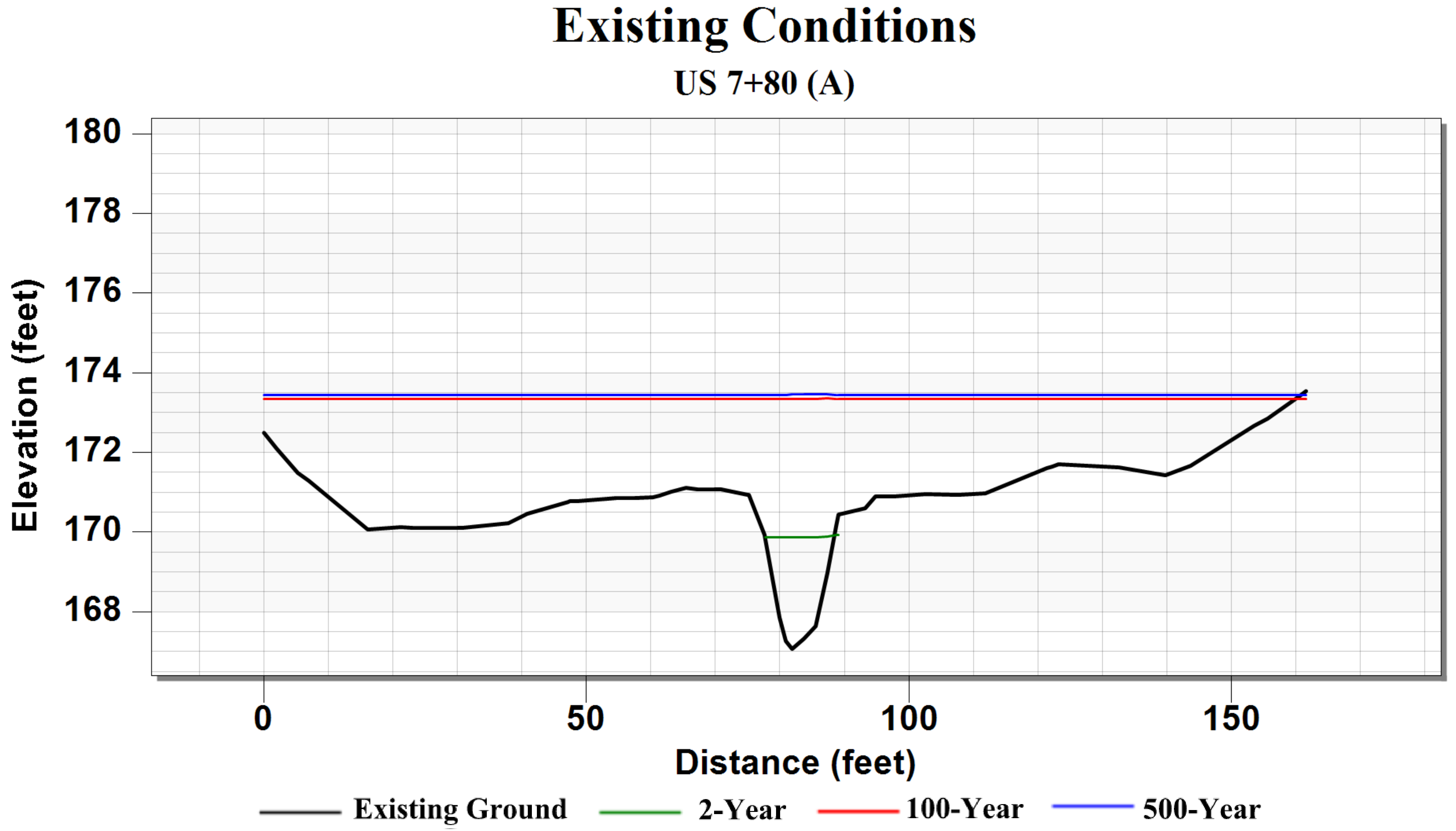


Figure H.50: Existing conditions water surface elevation STA 7+80

Natural Conditions SRH-2D Results

Cross Sections

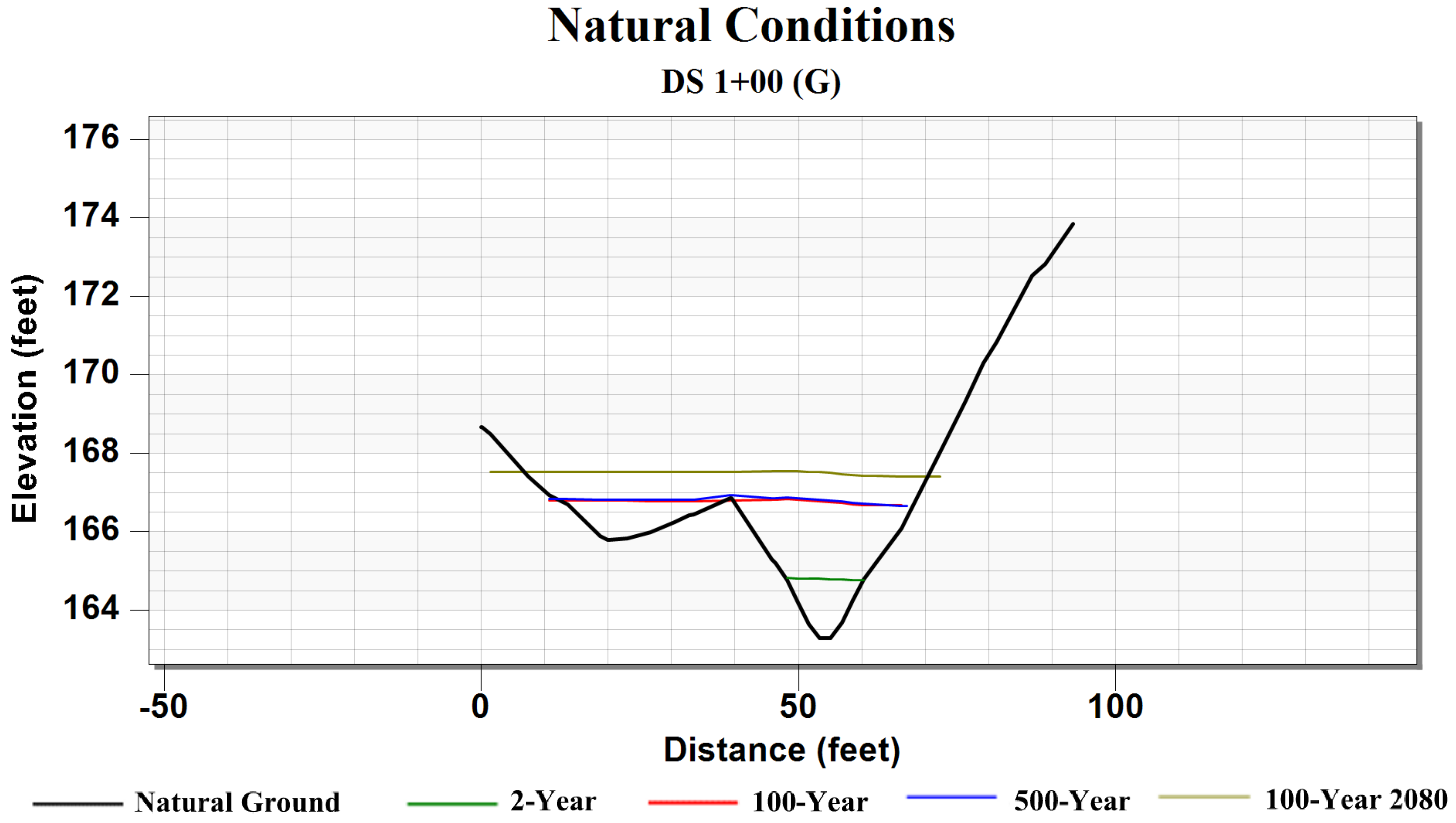


Figure H.51: Natural conditions water surface elevation STA 1+00

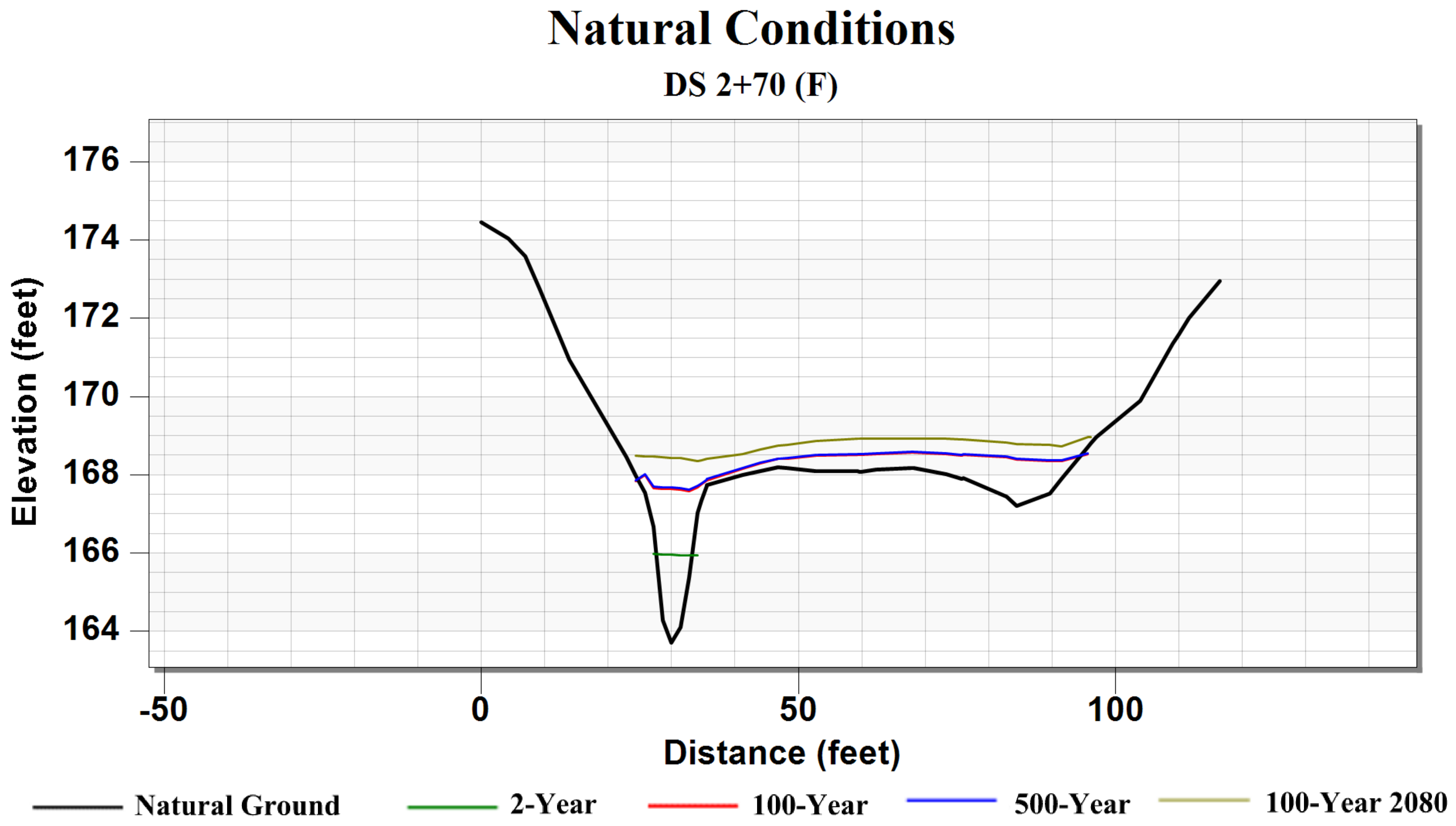


Figure H.52: Natural conditions water surface elevation STA 2+70

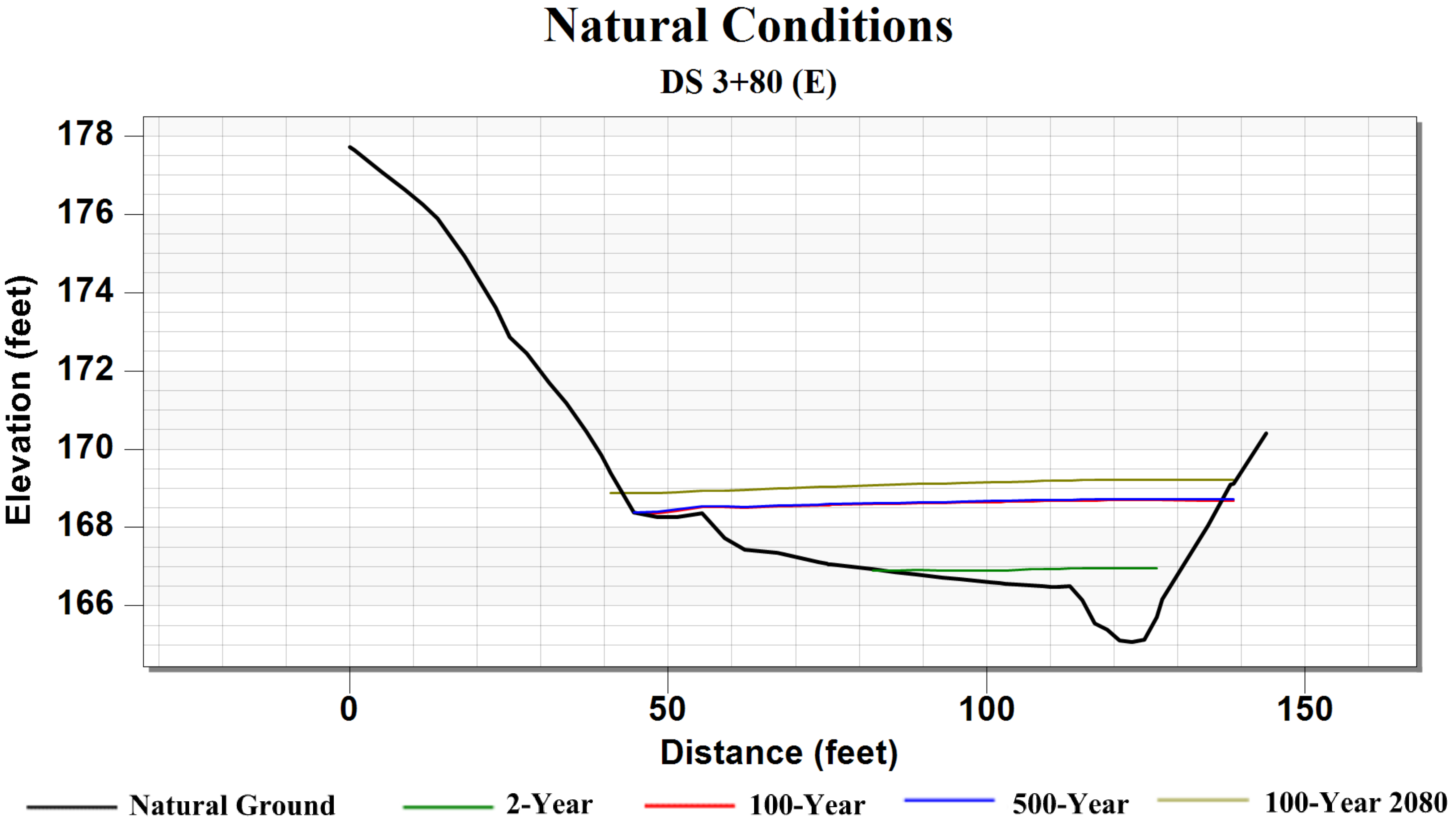


Figure H.53: Natural conditions water surface elevation STA 3+80

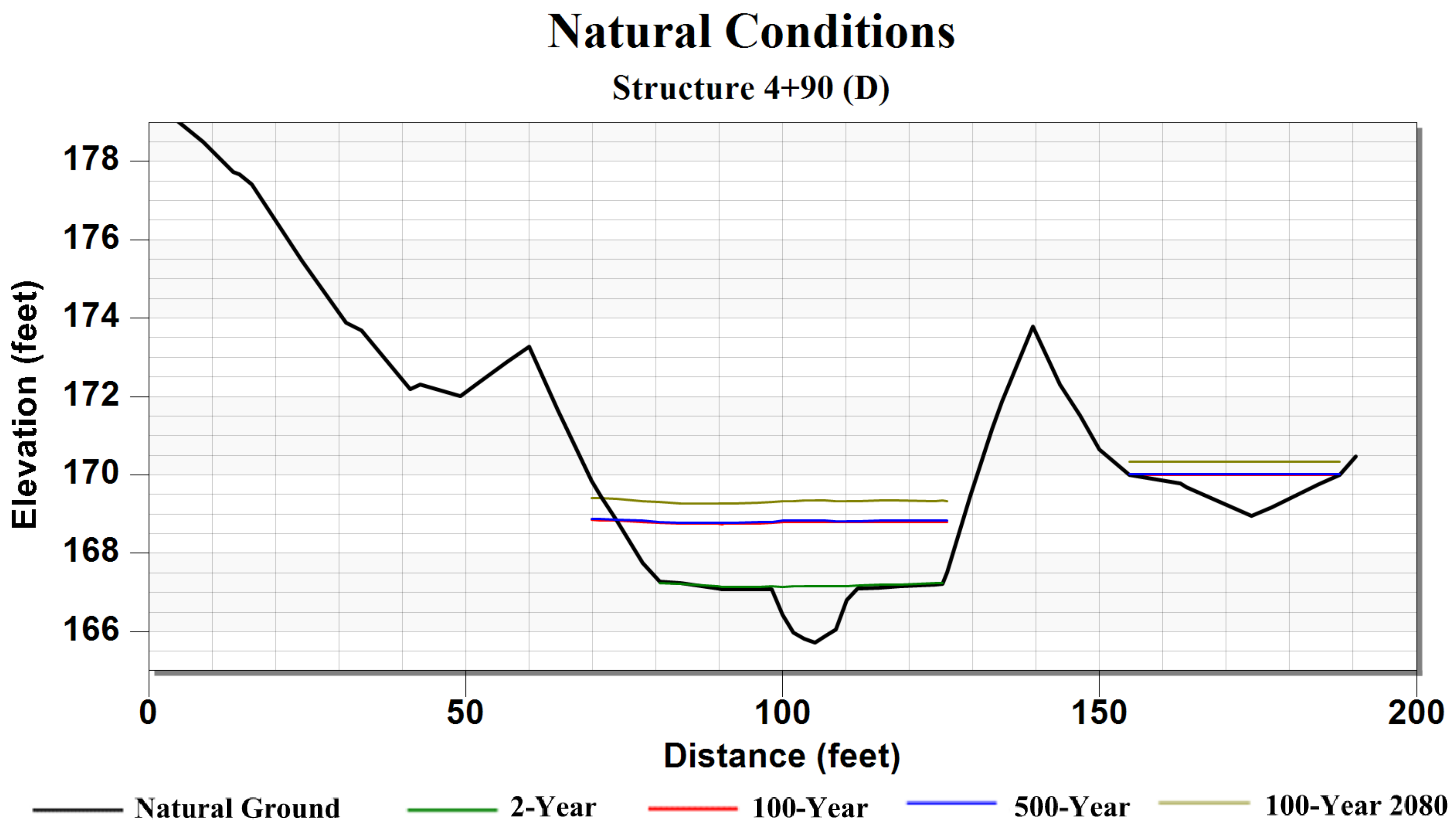


Figure H.54: Natural conditions water surface elevation STA 4+90

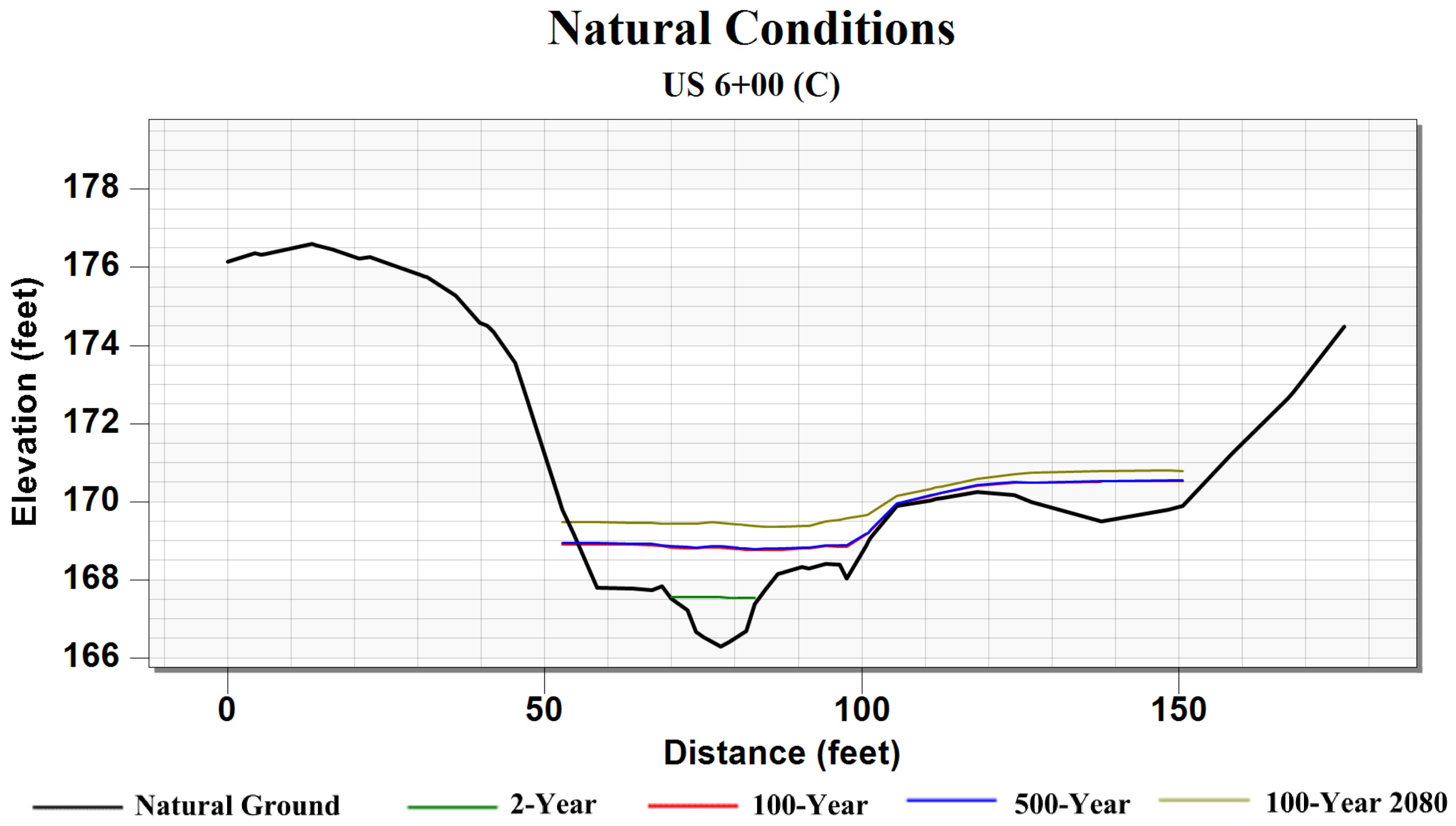


Figure H.55: Natural conditions water surface elevation STA 6+00

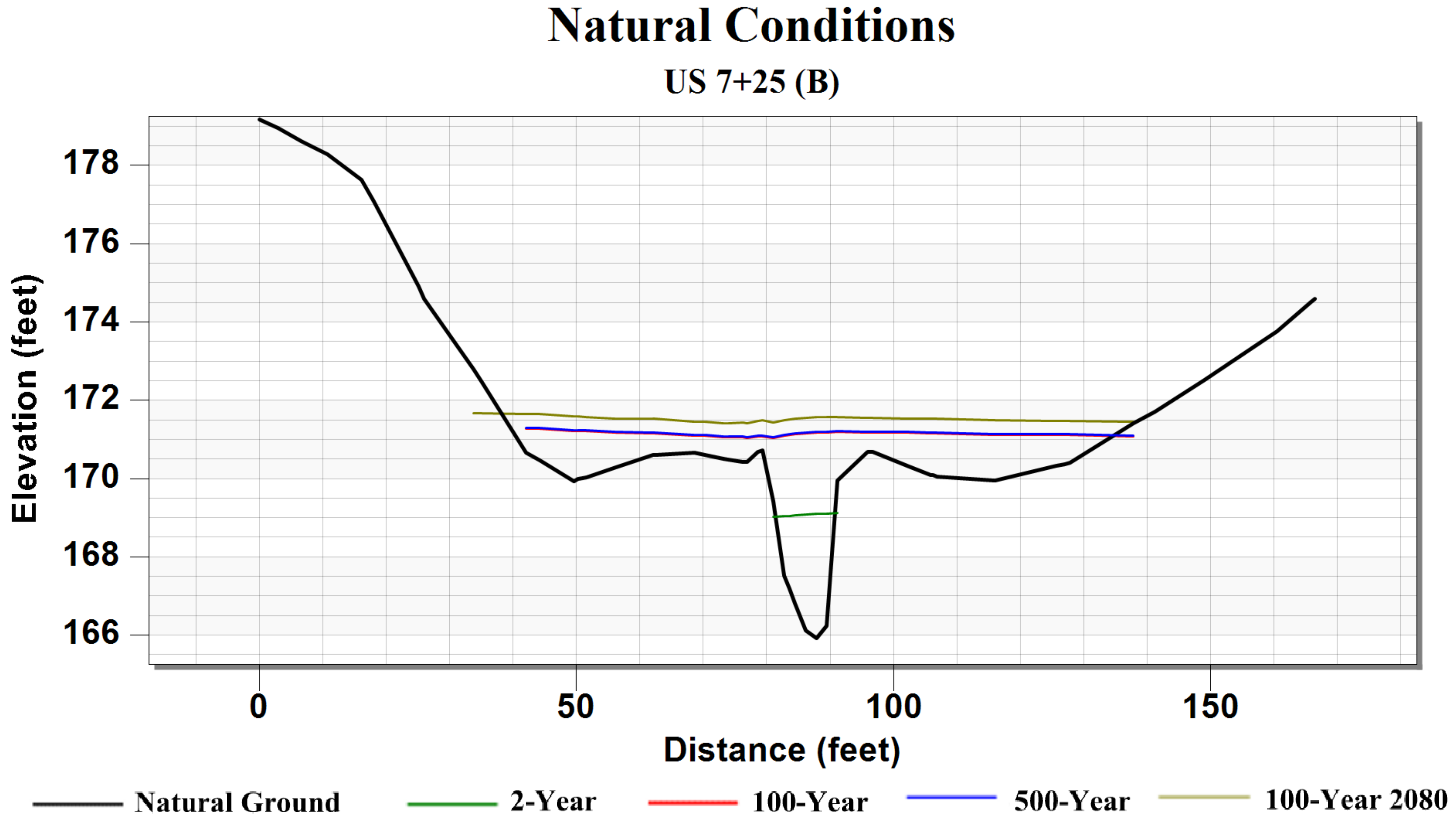


Figure H.56: Natural conditions water surface elevation STA 7+25

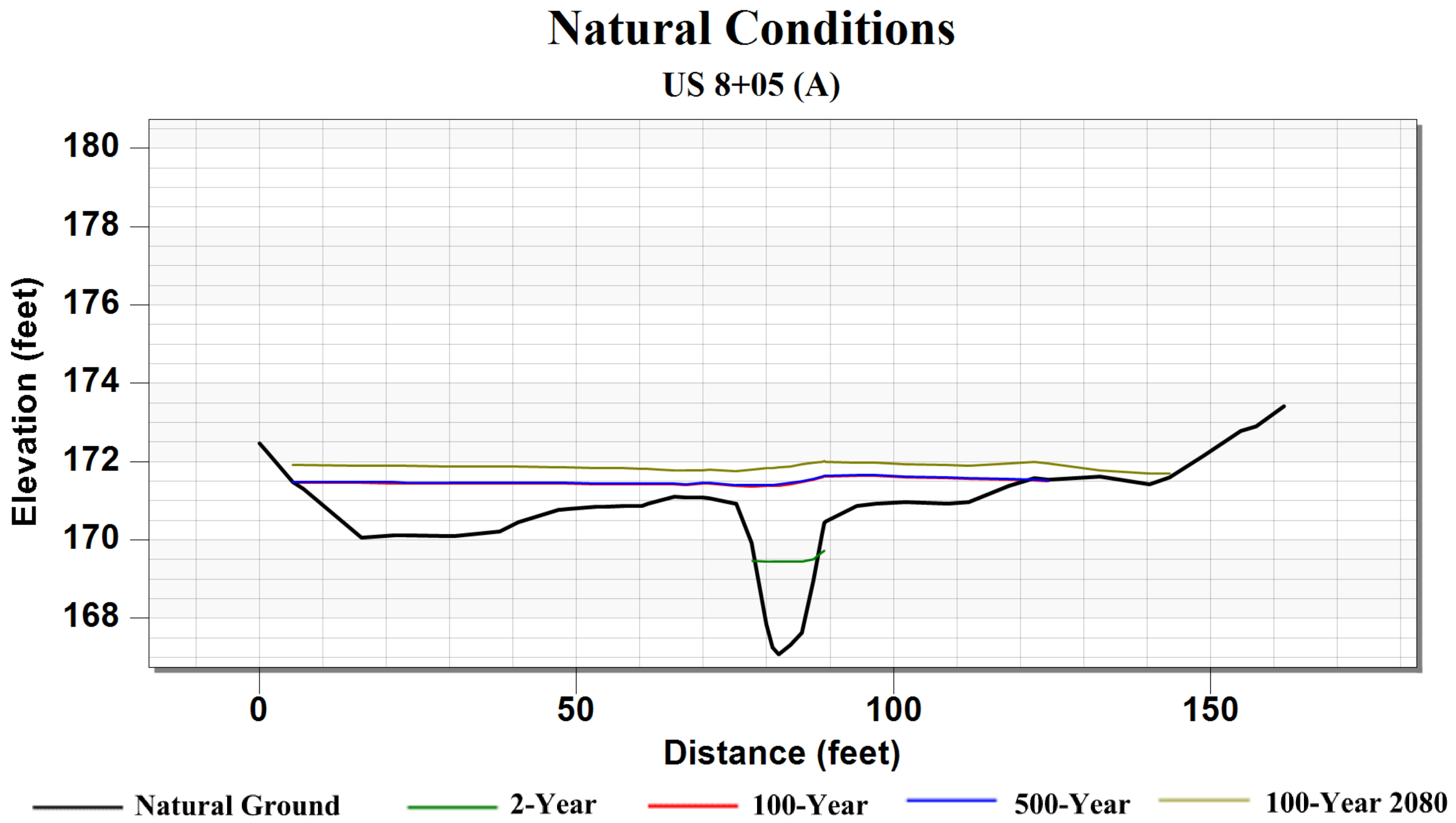


Figure H.57: Natural conditions water surface elevation STA 8+05

Proposed Conditions SRH-2D Results

Cross Sections

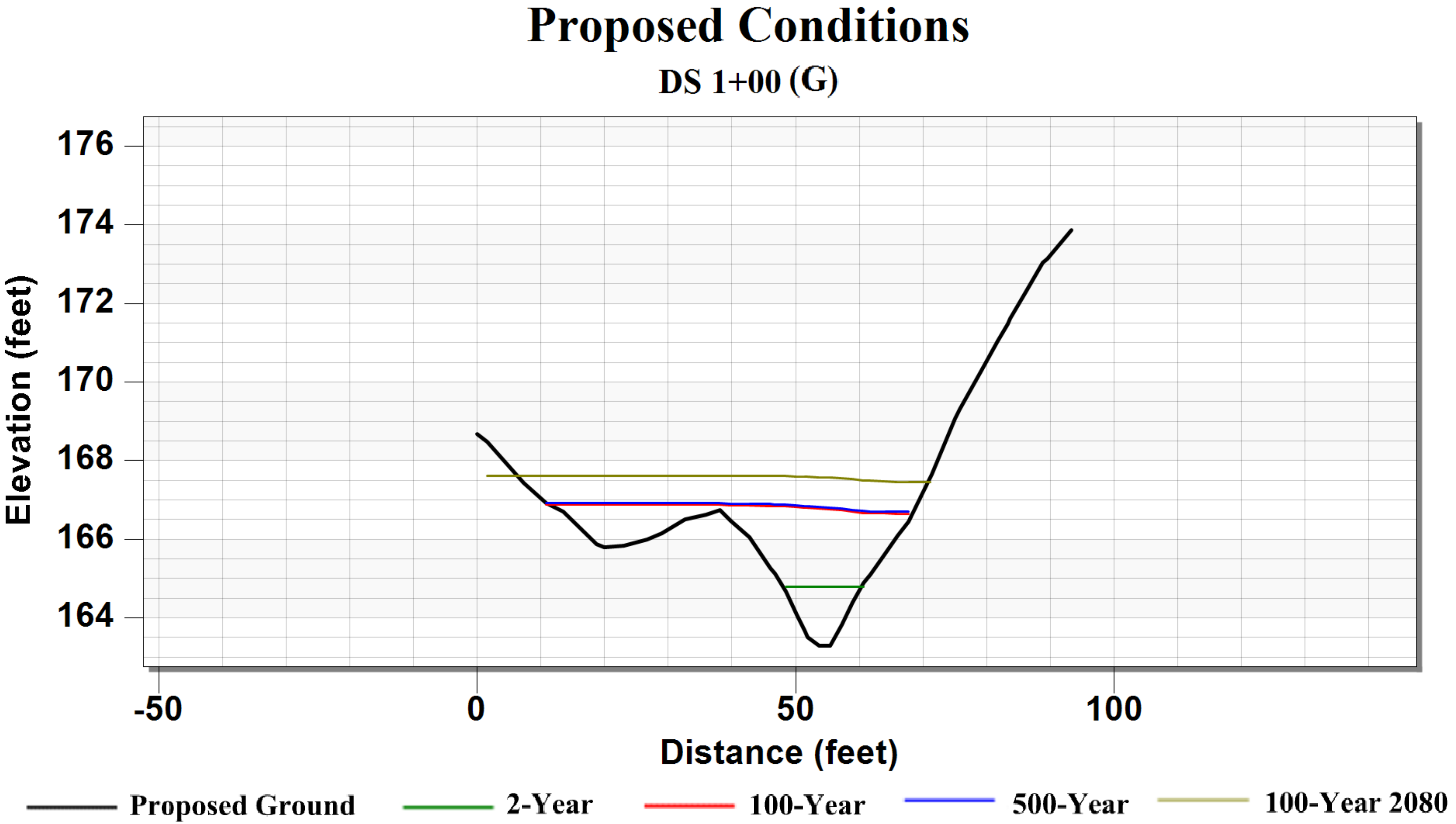


Figure H.58: Proposed conditions water surface elevation STA 1+00

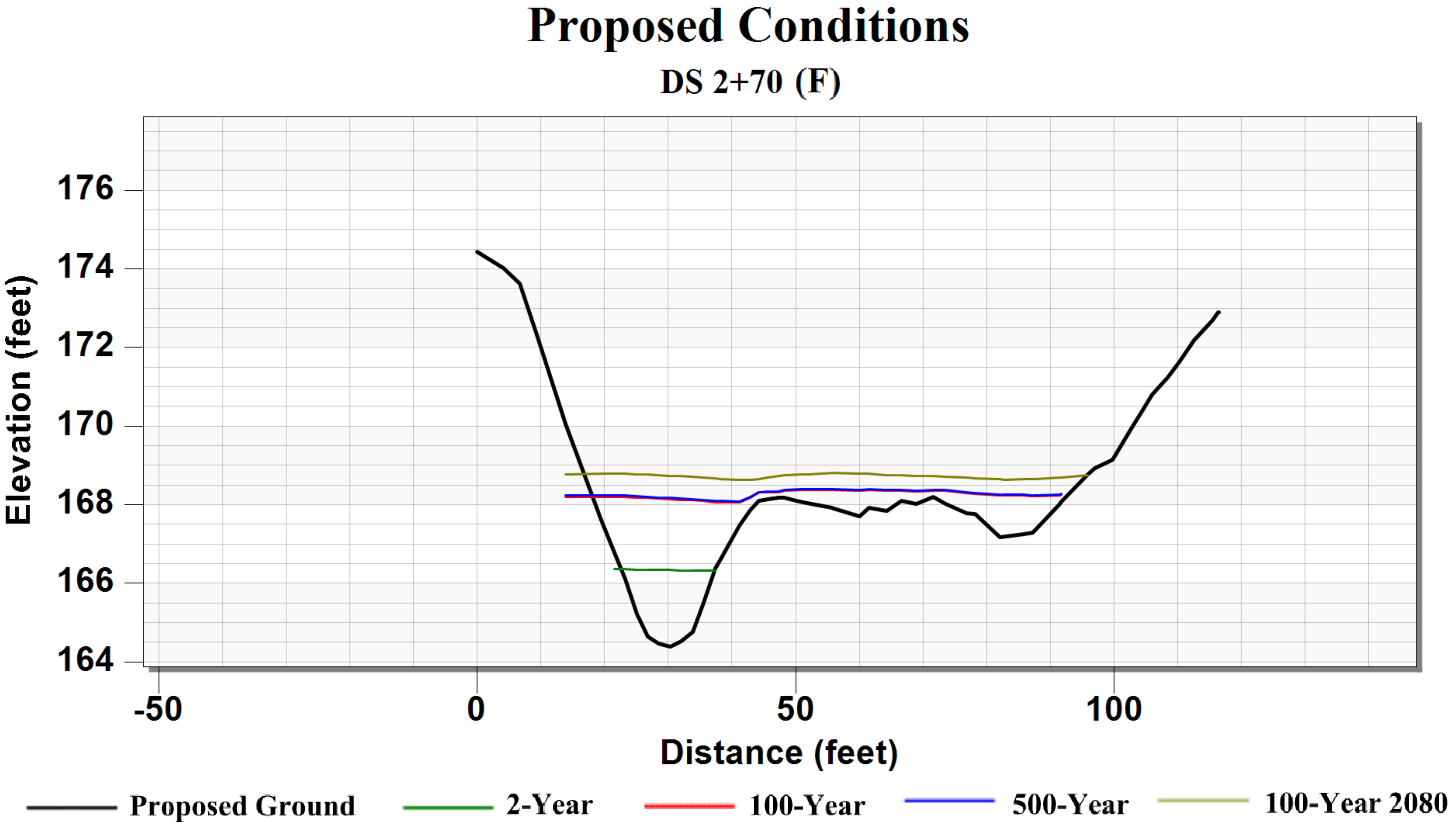


Figure H.59: Proposed conditions water surface elevation STA 2+70

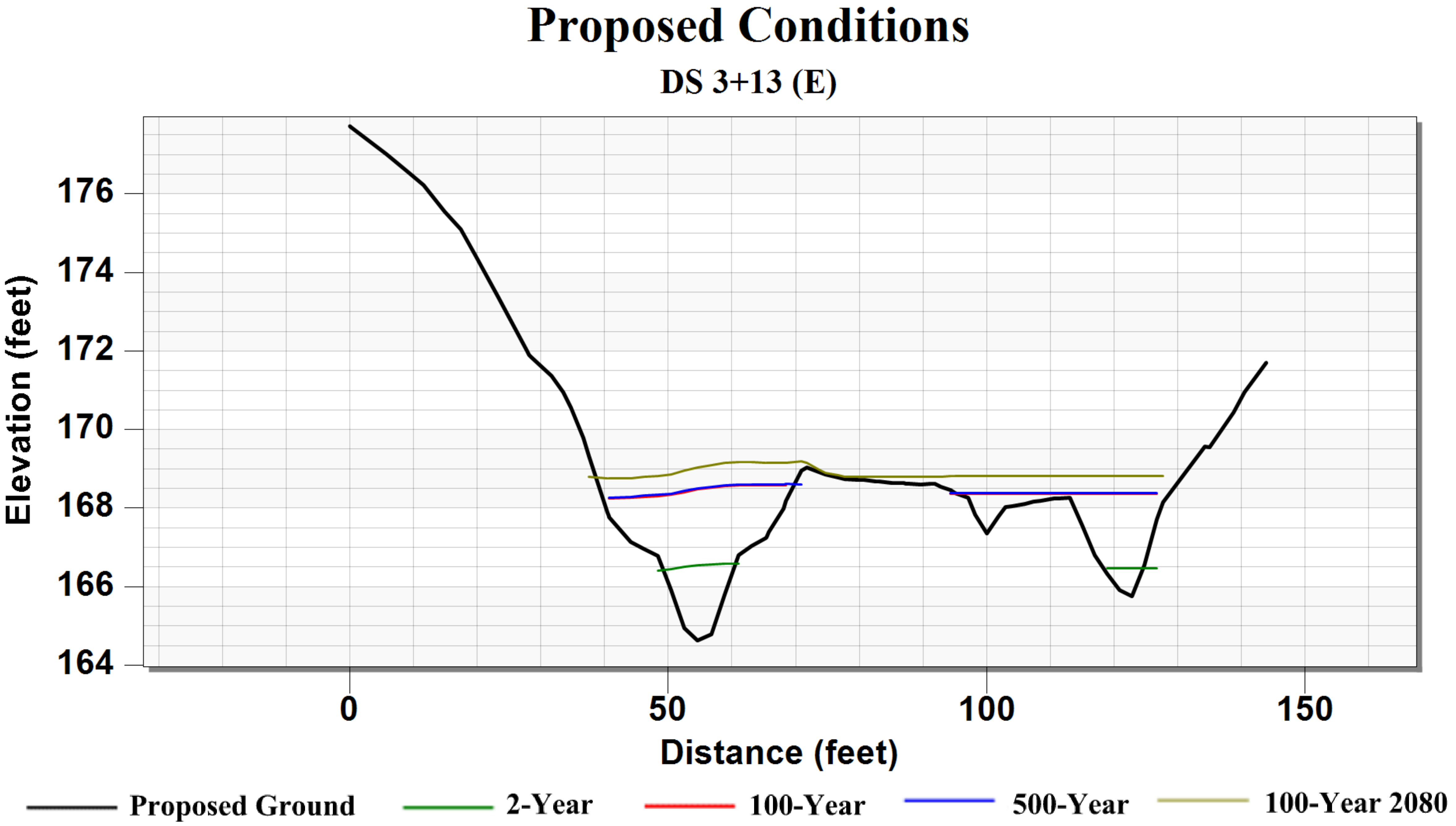


Figure H.60: Proposed conditions water surface elevation STA 3+13

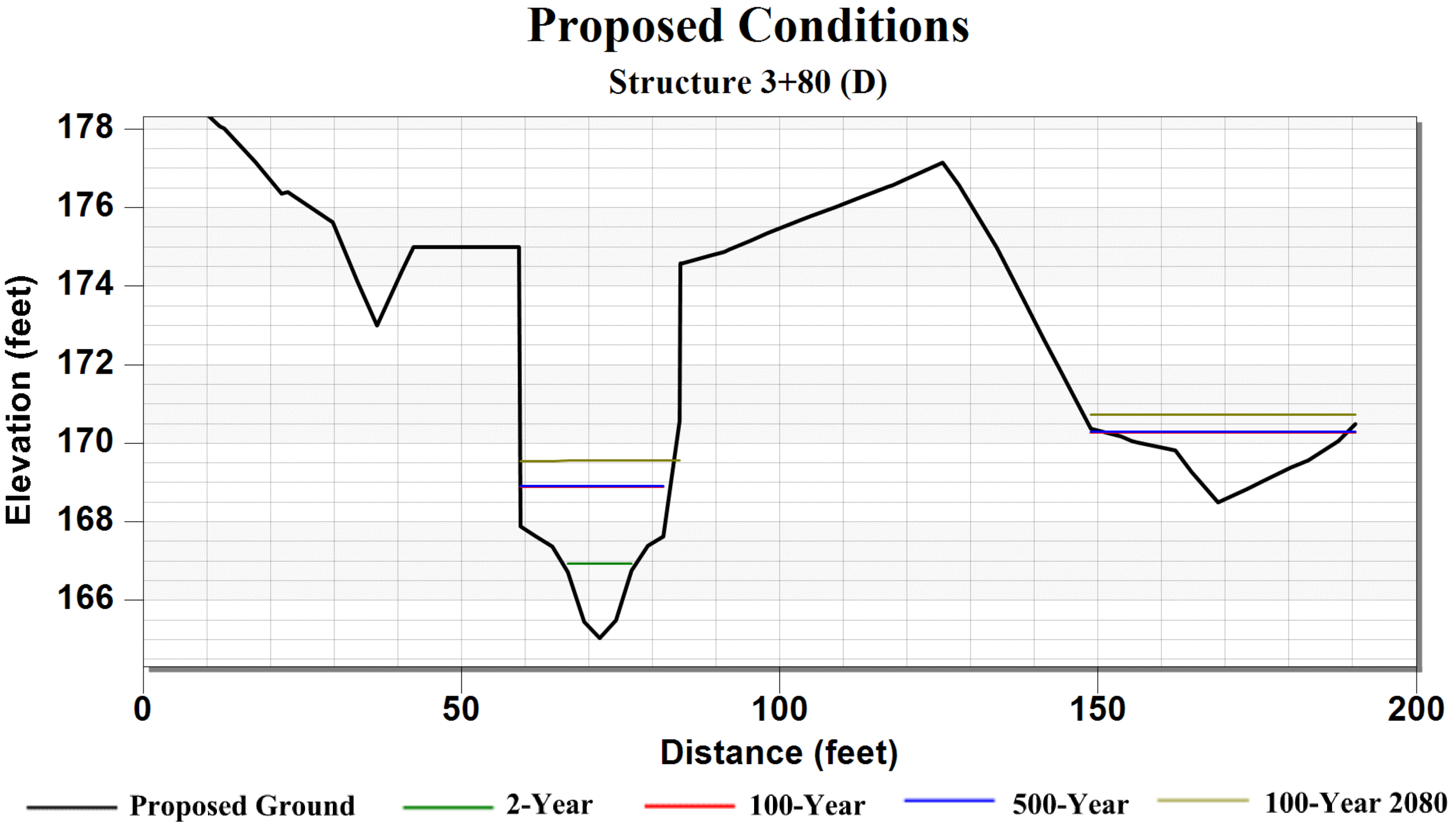


Figure H.61: Proposed conditions water surface elevation STA 3+80

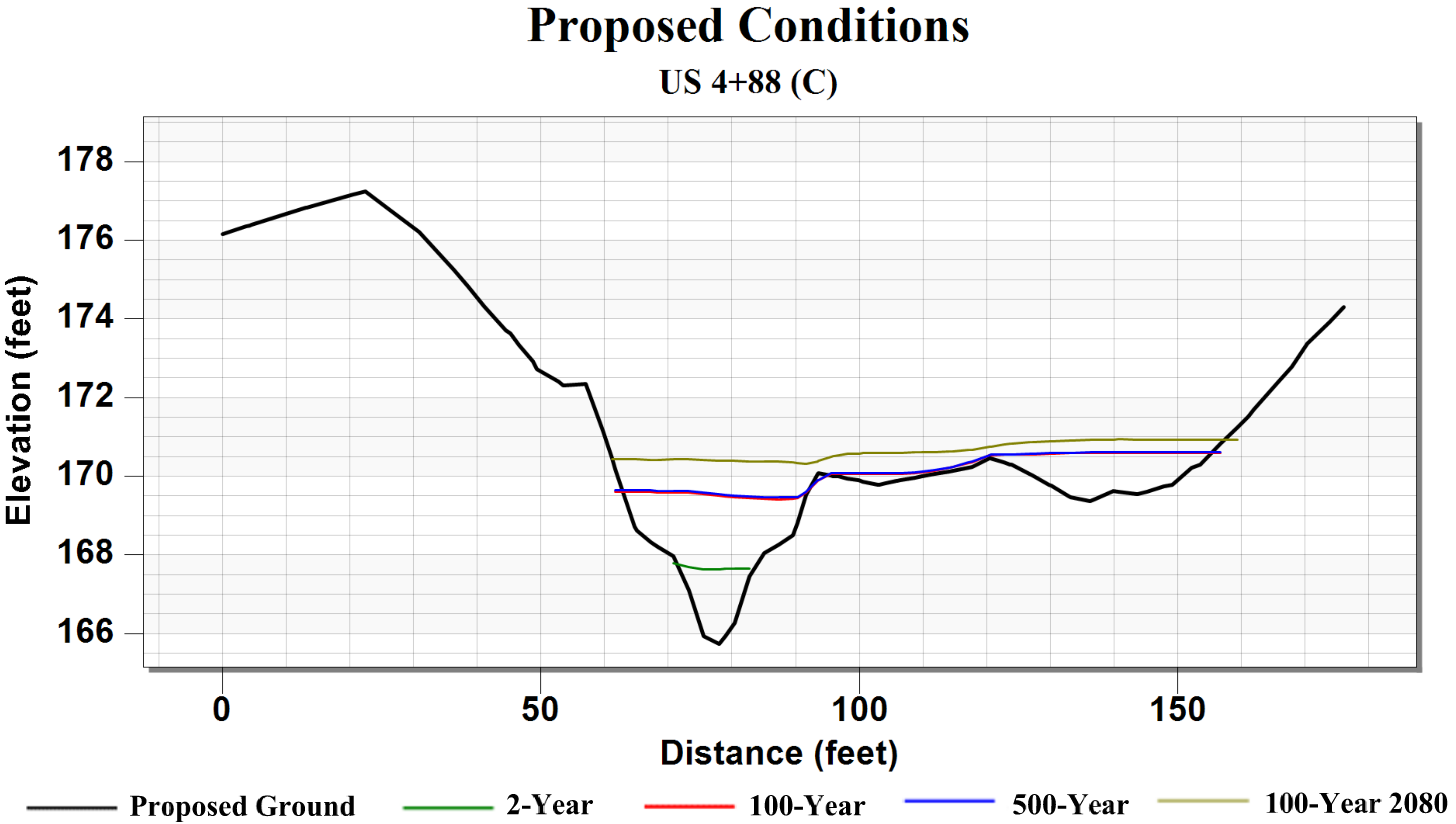


Figure H.62: Proposed conditions water surface elevation STA 4+88

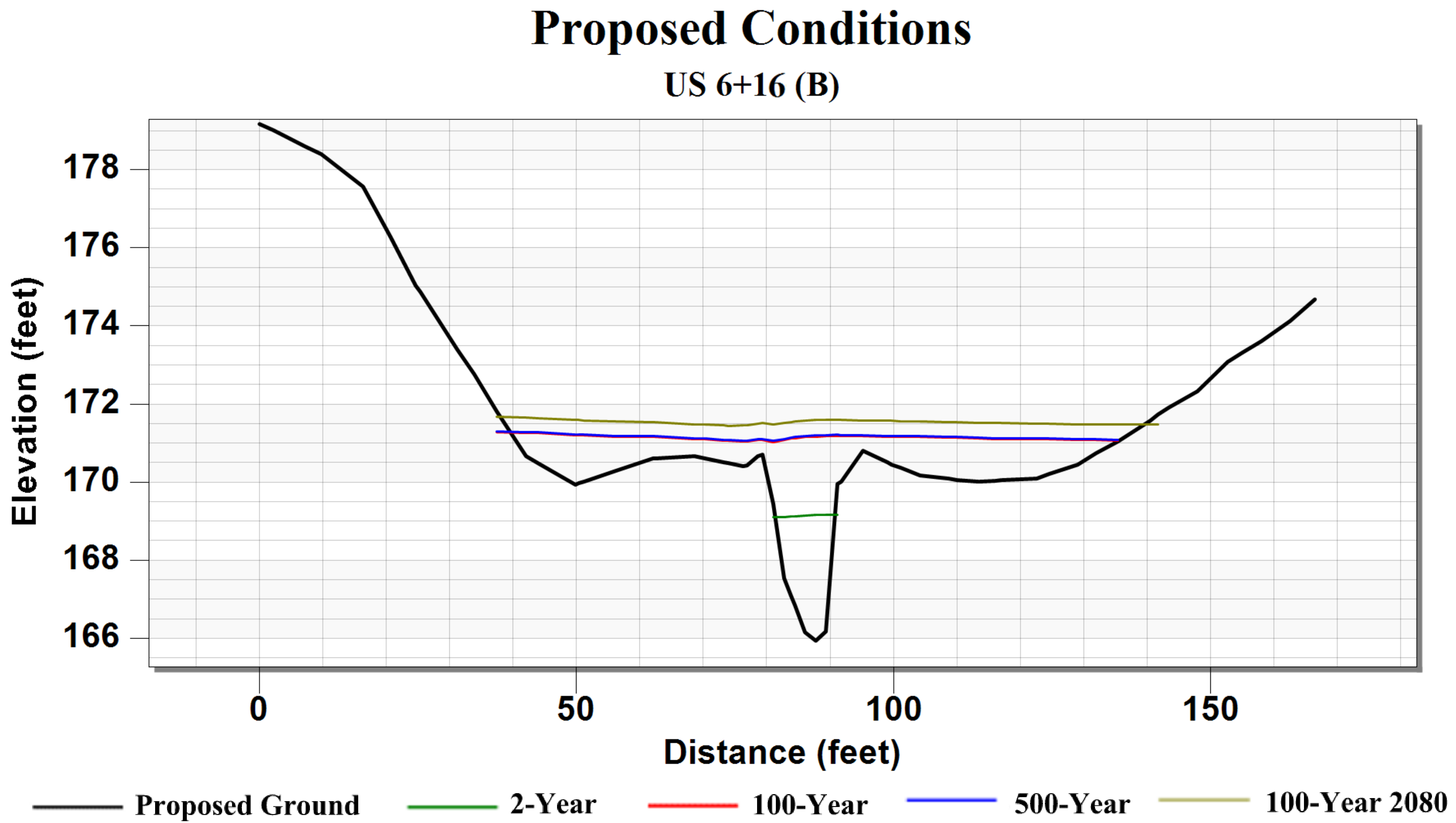


Figure H.63: Proposed conditions water surface elevation STA 6+16

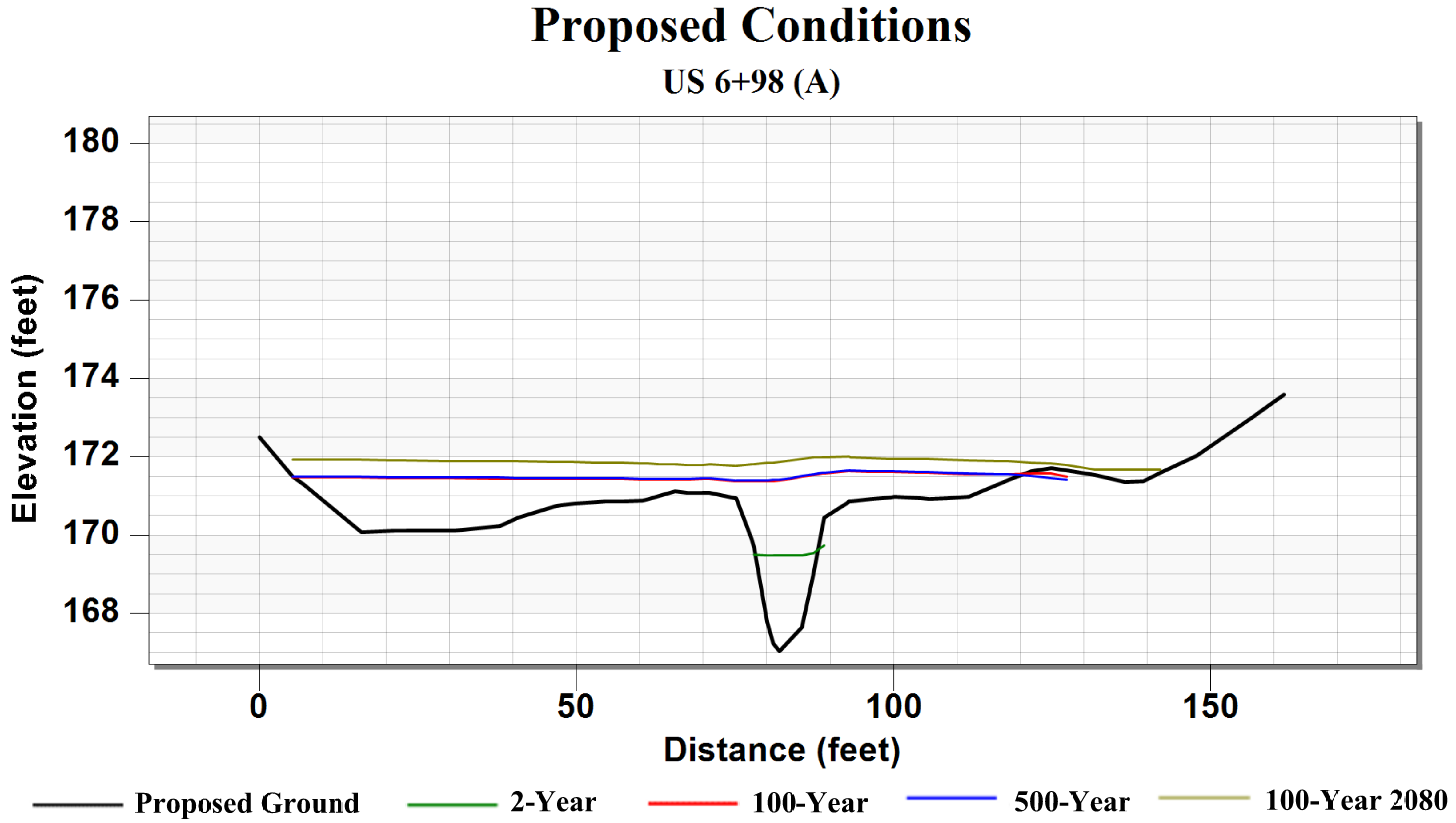
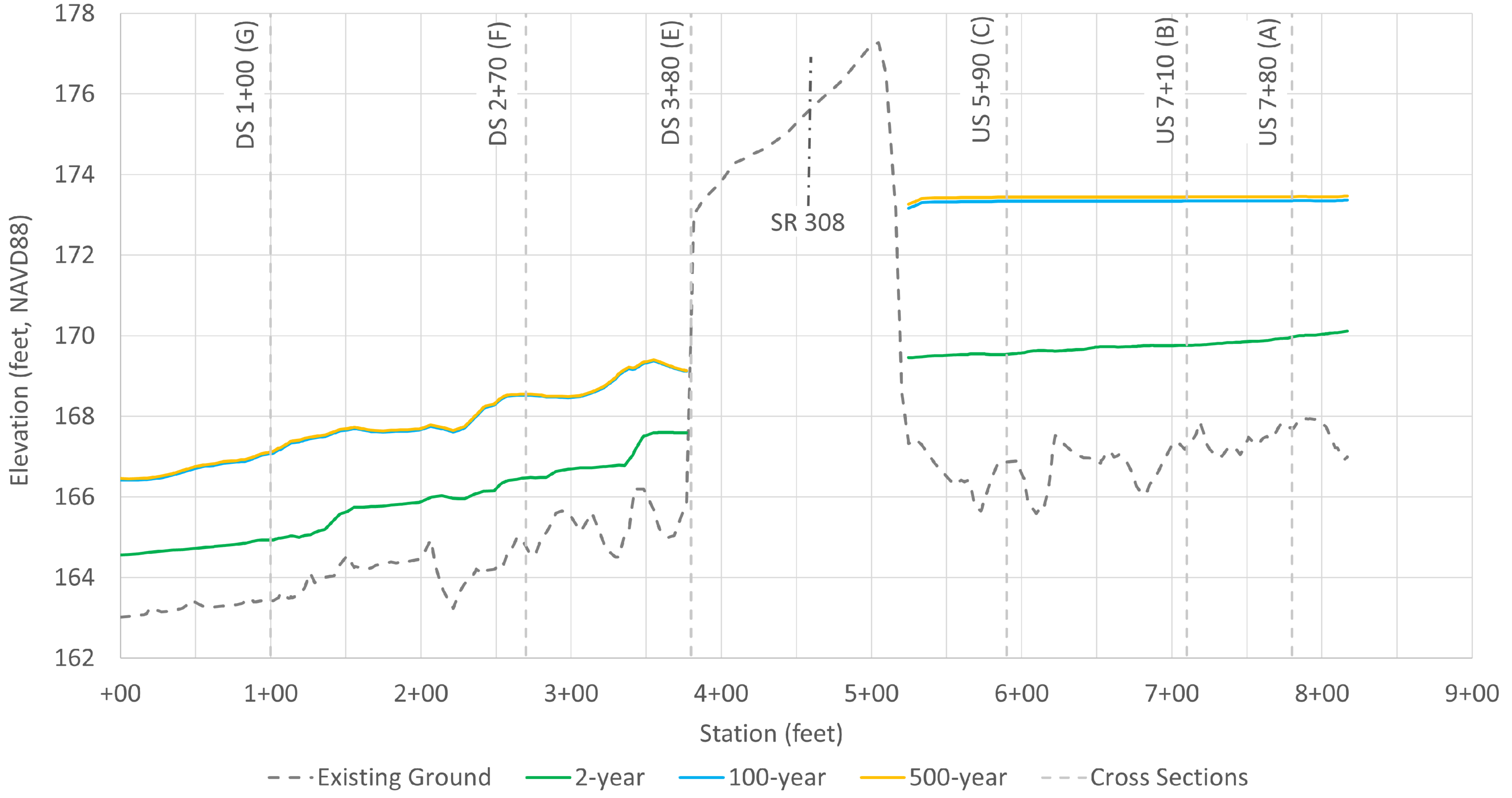


Figure H.64: Proposed conditions water surface elevation STA 6+98

Existing Conditions SRH-2D Results

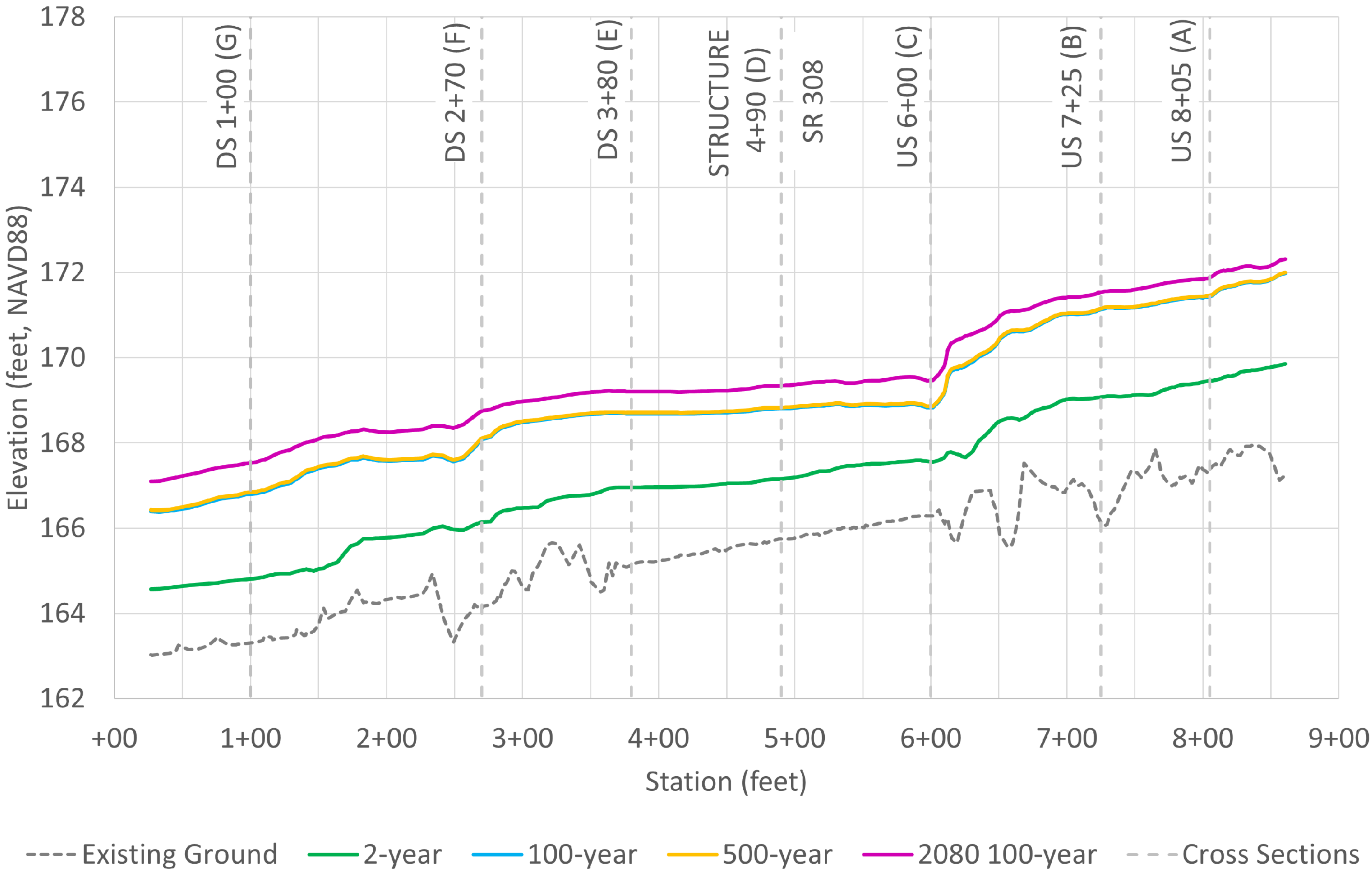
Water Surface Profile



178
176
174
172
170
168
166
164
162
Elevation (feet, NAVD88)
DS 1+00 (G)
DS 2+70 (F)
DS 3+80 (E)
SR 308
US 5+90 (C)
US 7+10 (B)
US 7+80 (A)
+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
Station (feet)
Existing Ground
2-year
100-year
500-year
Cross Sections

Natural Conditions SRH-2D Results

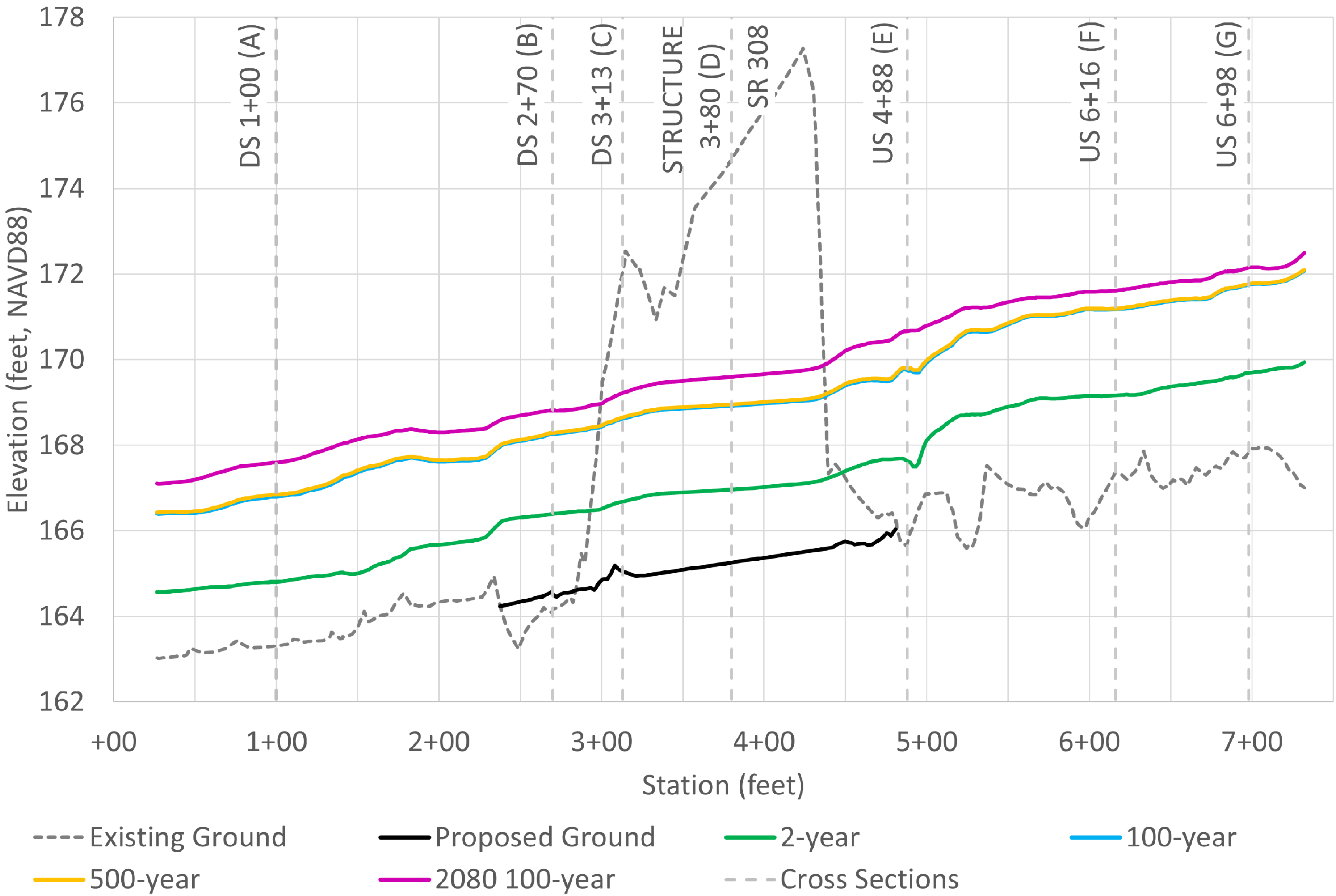
Water Surface Profile



178
176
174
172
170
168
166
164
162
Elevation (feet, NAVD88)
DS 1+00 (G)
DS 2+70 (F)
DS 3+80 (E)
STRUCTURE 4+90 (D)
SR 308
US 6+00 (C)
US 7+25 (B)
US 8+05 (A)
+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
Station (feet)
Existing Ground
2-year
100-year
500-year
2080 100-year
Cross Sections

Proposed Conditions SRH-2D Results

Water Surface Profile



178
176
174
172
170
168
166
164
162
Elevation (feet, NAVD88)
DS 1+00 (A)
DS 2+70 (B)
DS 3+13 (C)
STRUCTURE
3+80 (D)
SR 308
US 4+88 (E)
US 6+16 (F)
US 6+98 (G)
+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
Station (feet)
Existing Ground
Proposed Ground
2-year
100-year
500-year
2080 100-year
Cross Sections

Appendix I: SRH-2D Model Stability and Continuity

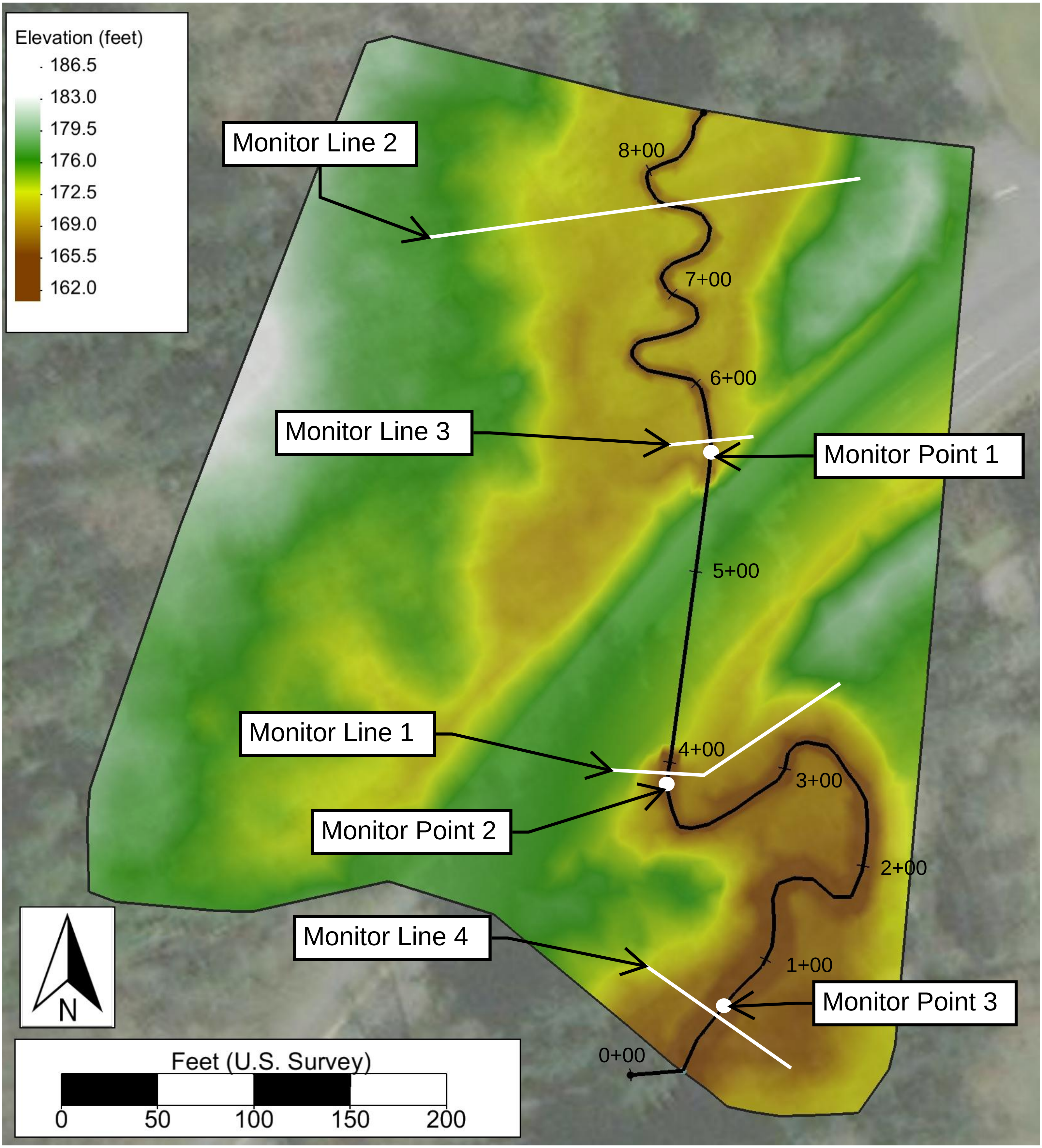


Figure I.1: Existing conditions monitor points and lines locations

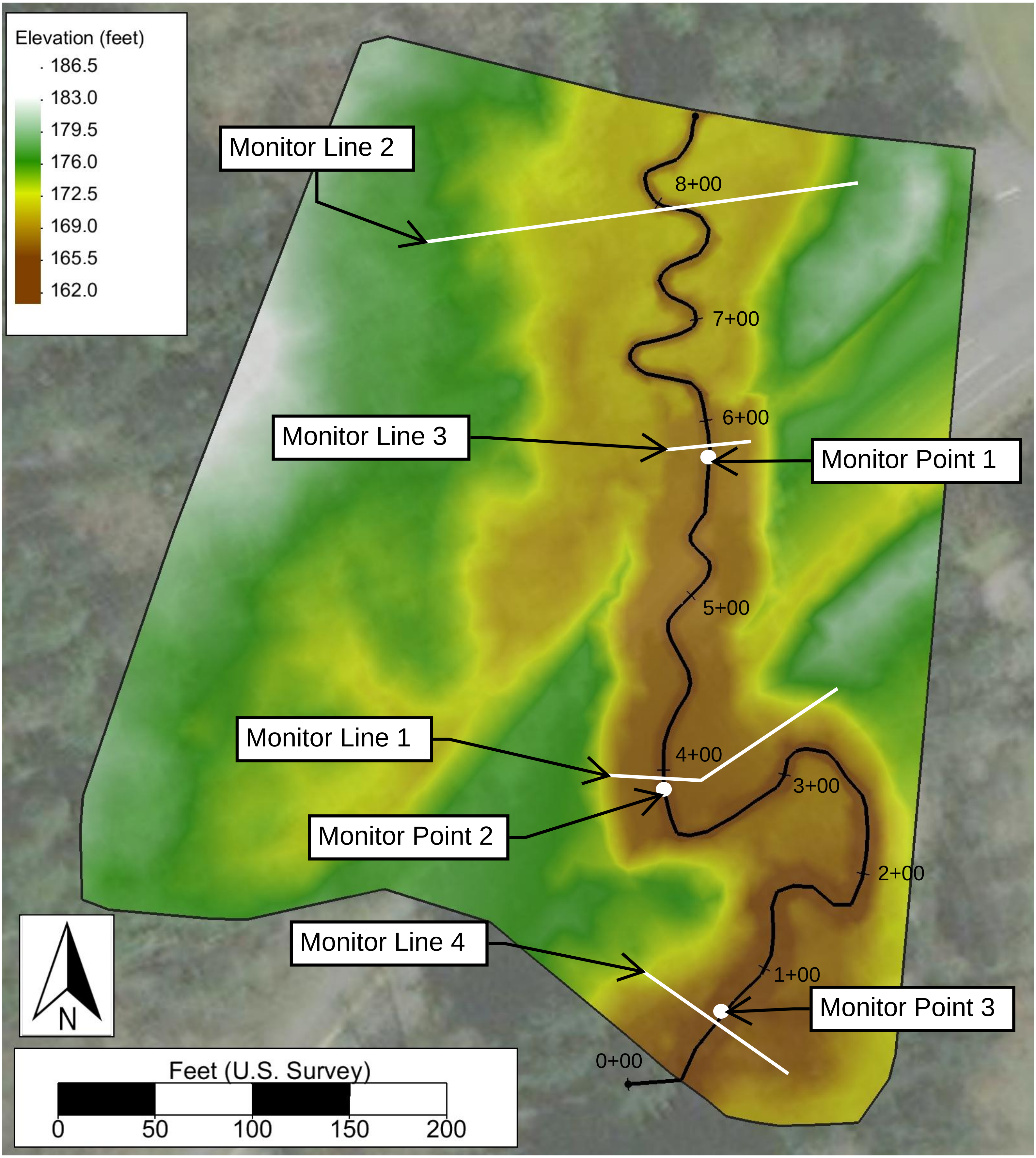


Figure I.2: Natural conditions monitor points and lines locations

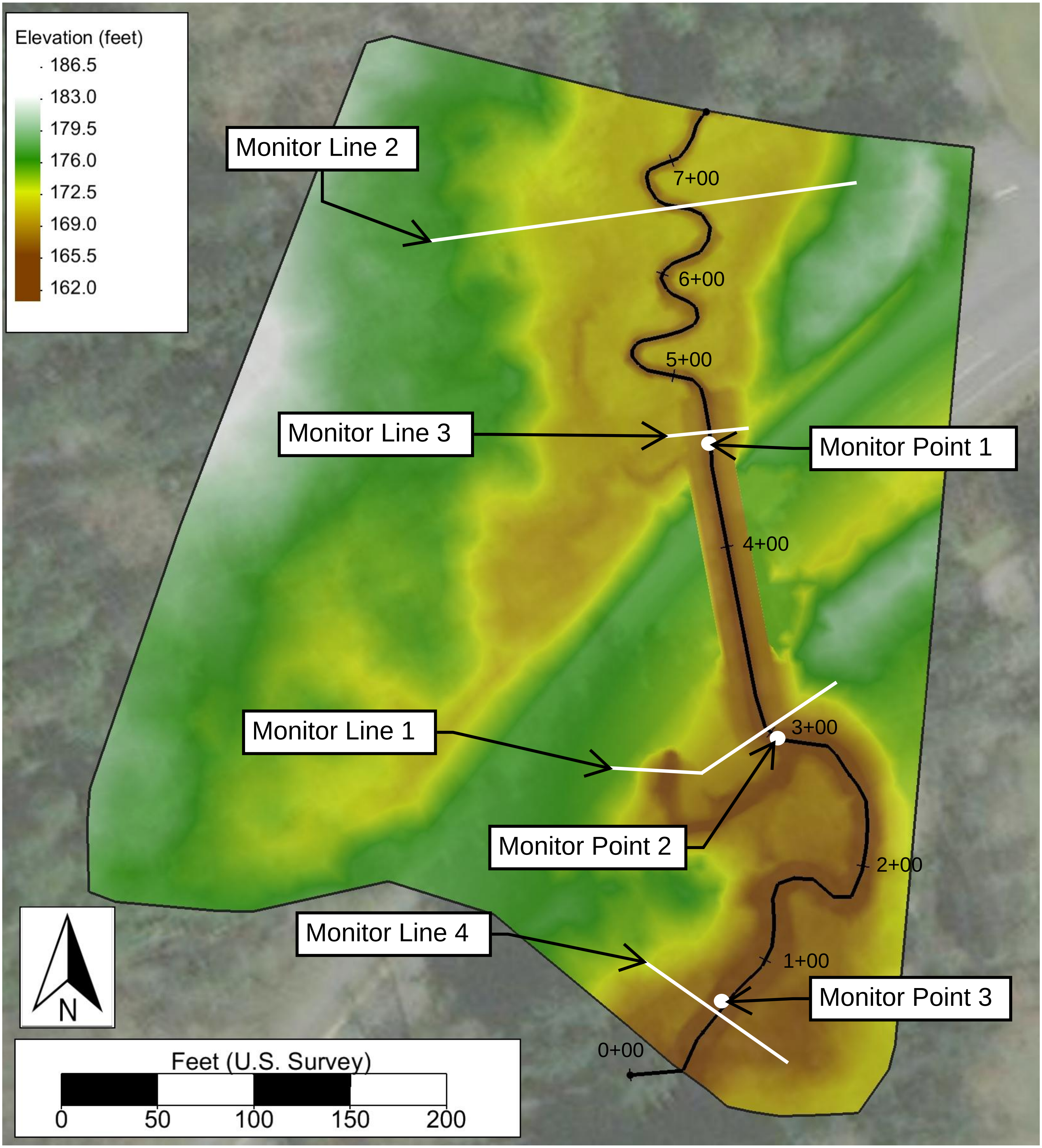


Figure I.3: Proposed conditions monitor points and lines locations

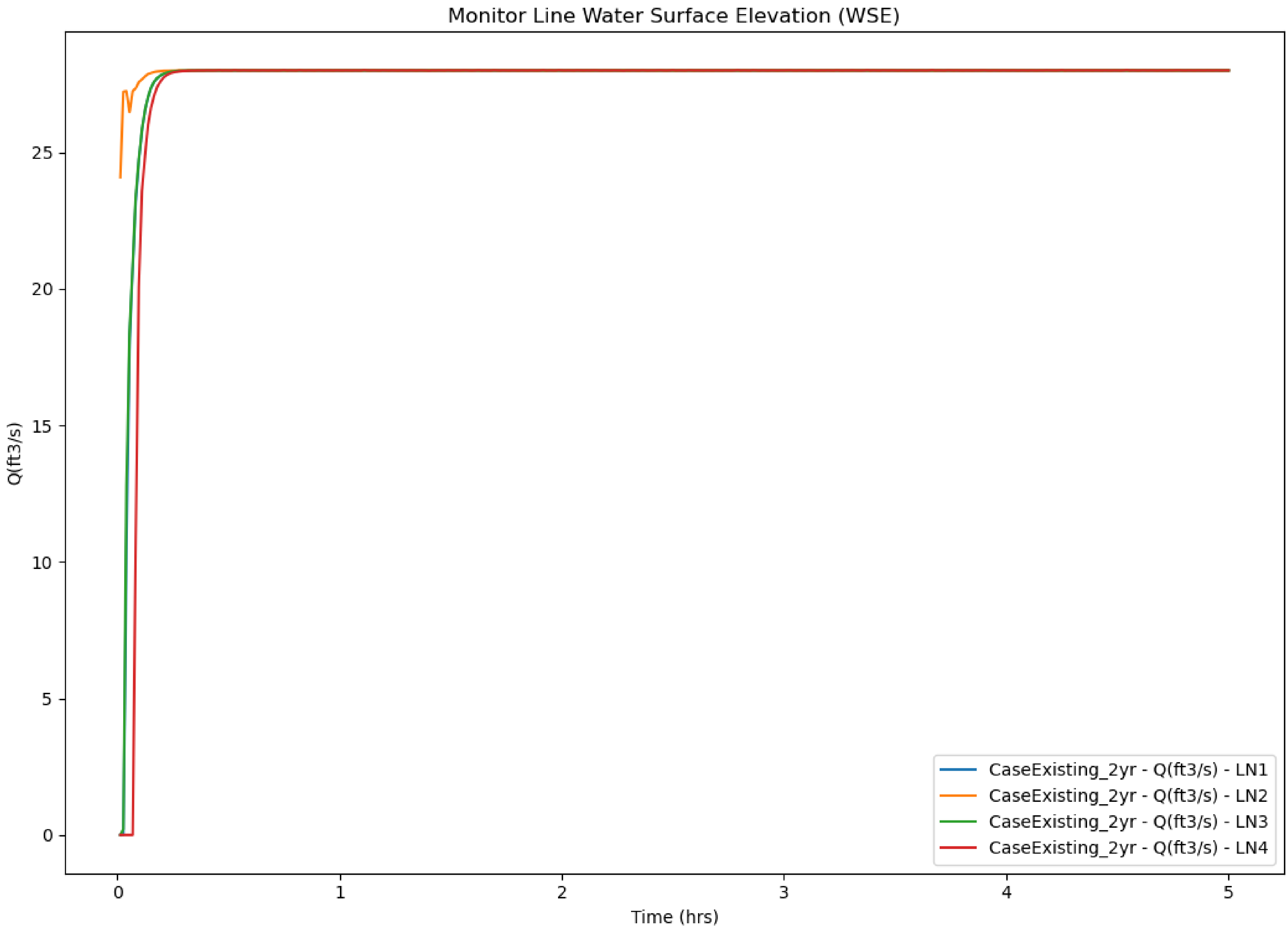


Figure I.4: Existing conditions 2-year monitor lines

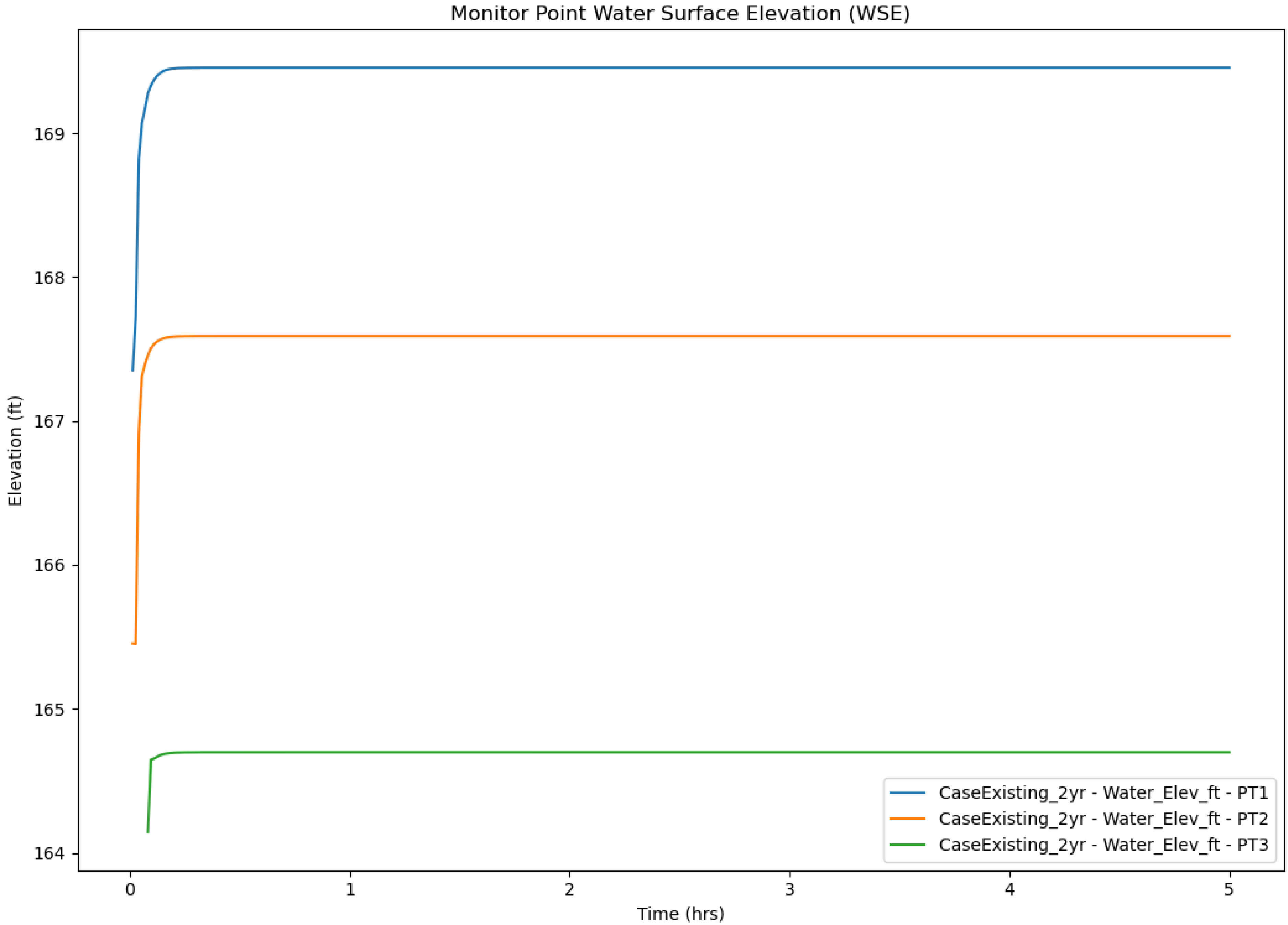


Figure I.5: Existing conditions 2-year monitor points

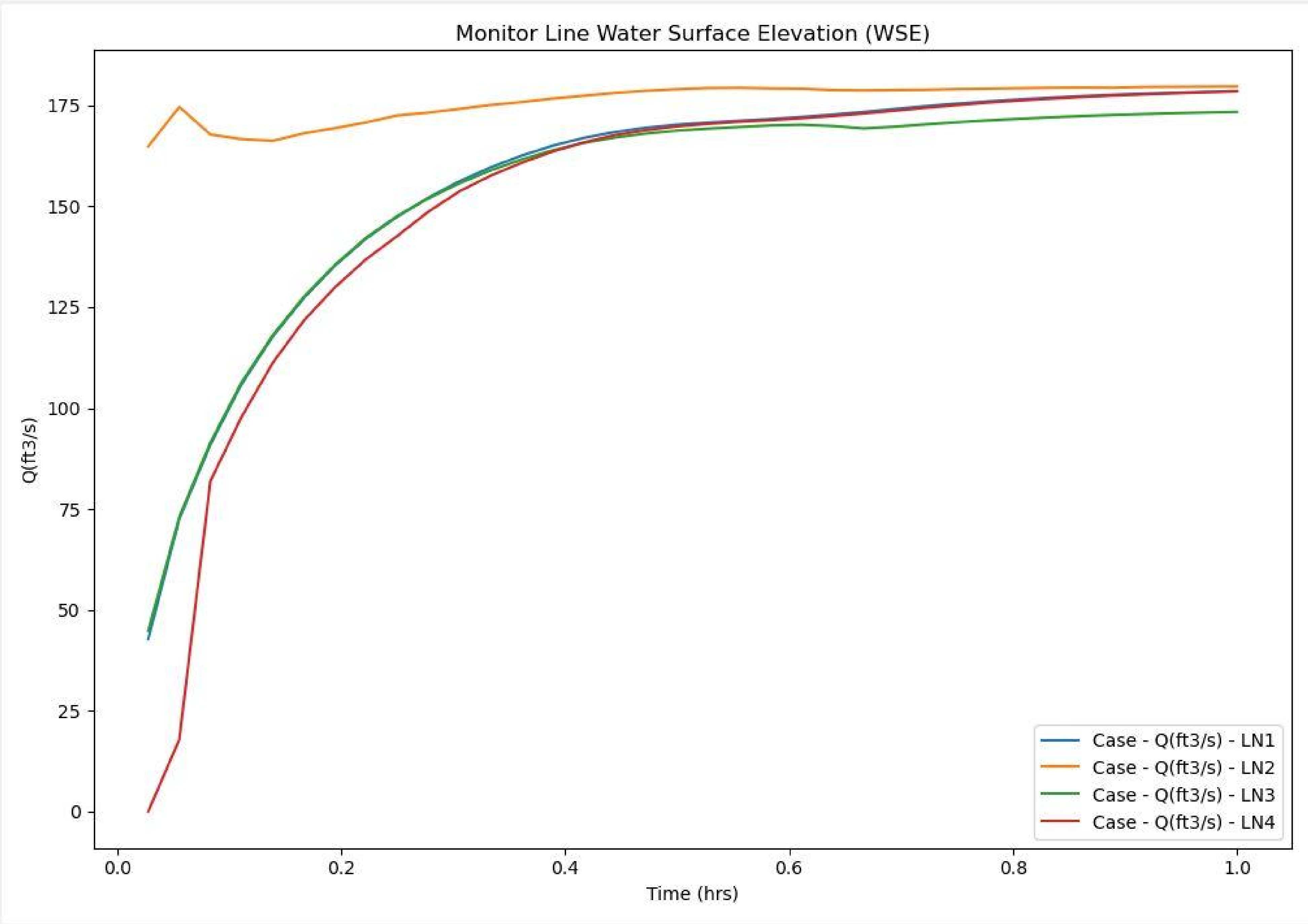


Figure I.6: Existing conditions 100-year monitor lines

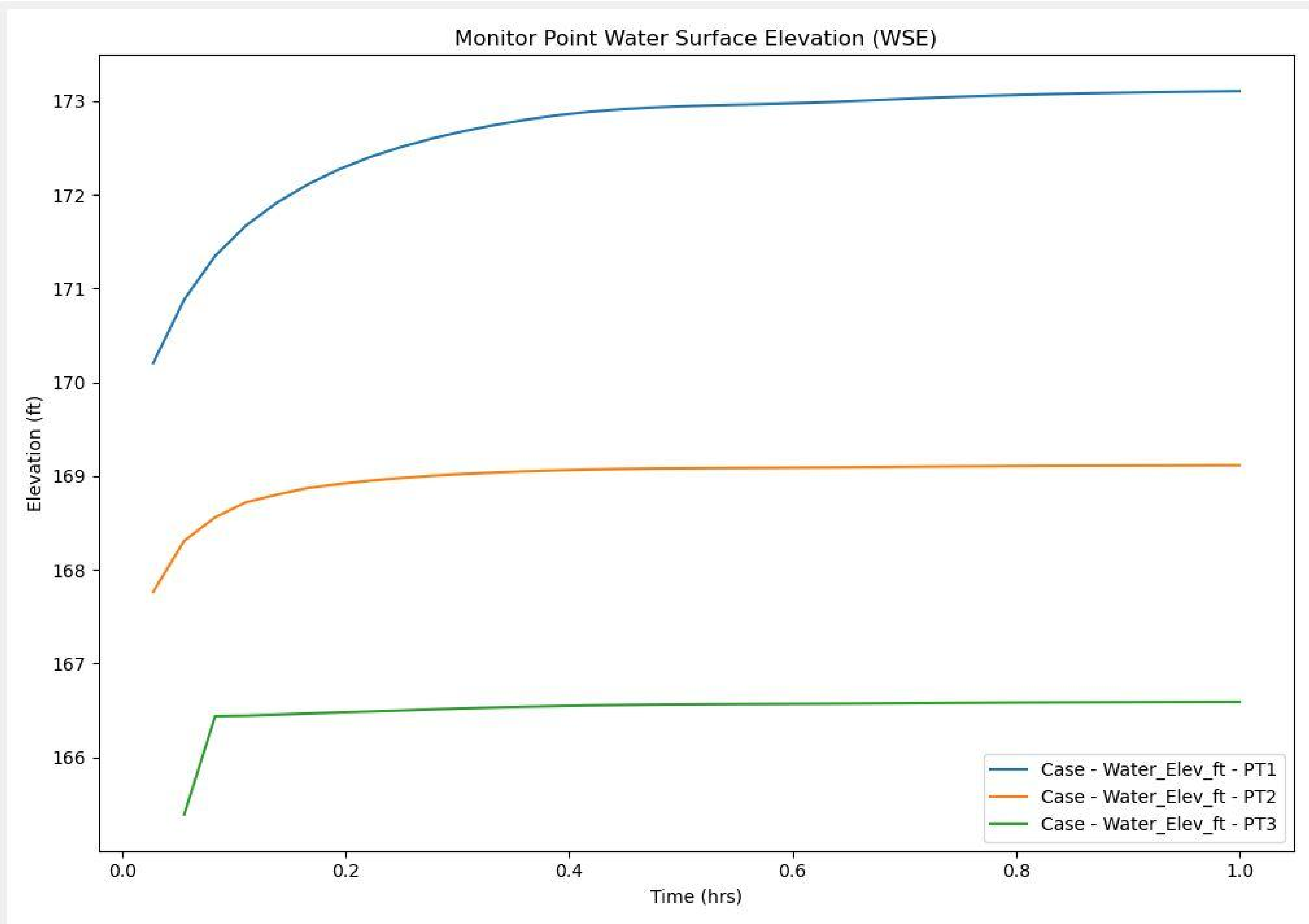


Figure I.7: Existing conditions 100-year monitor points

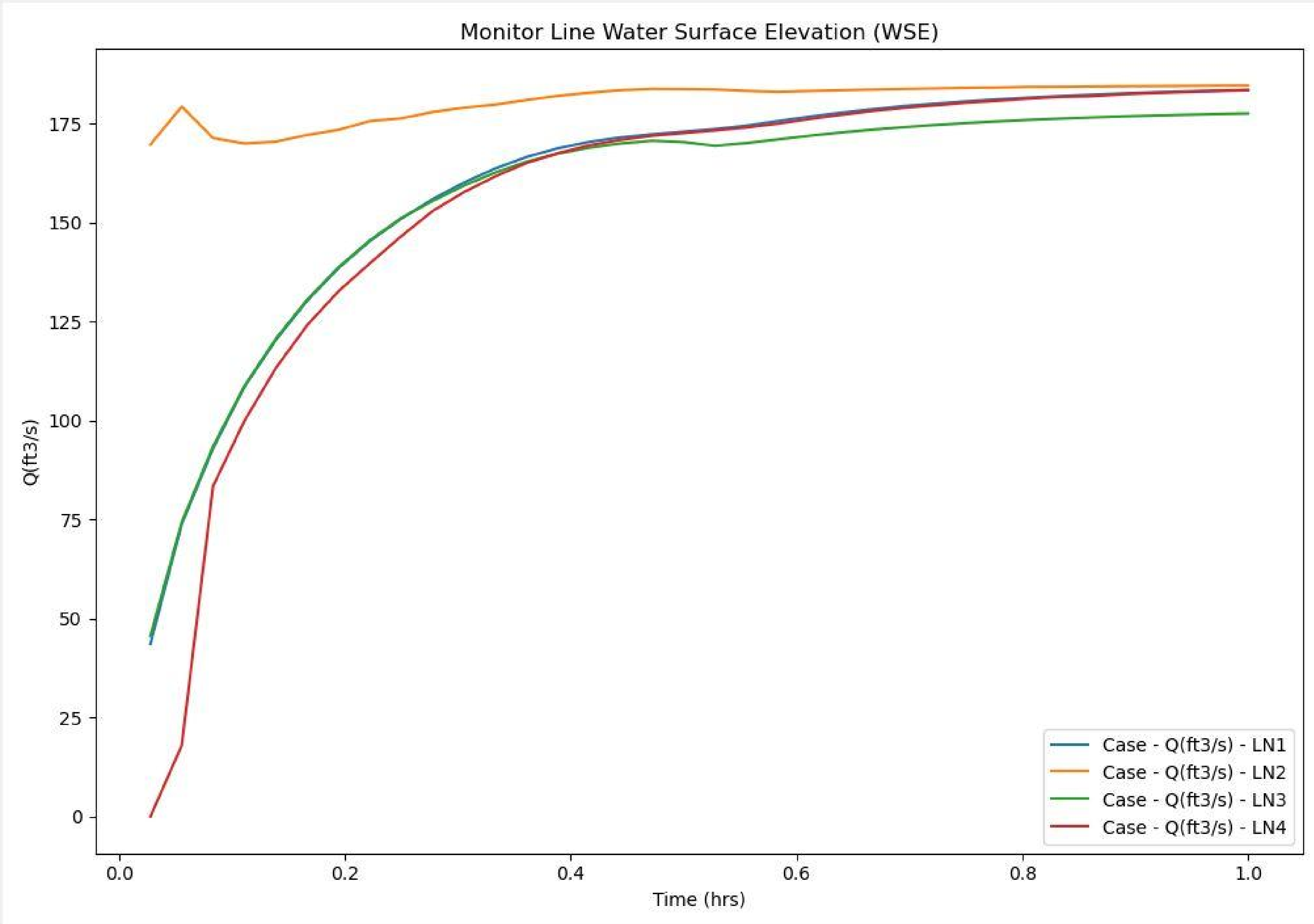


Figure I.8: Existing conditions 500-year monitor lines

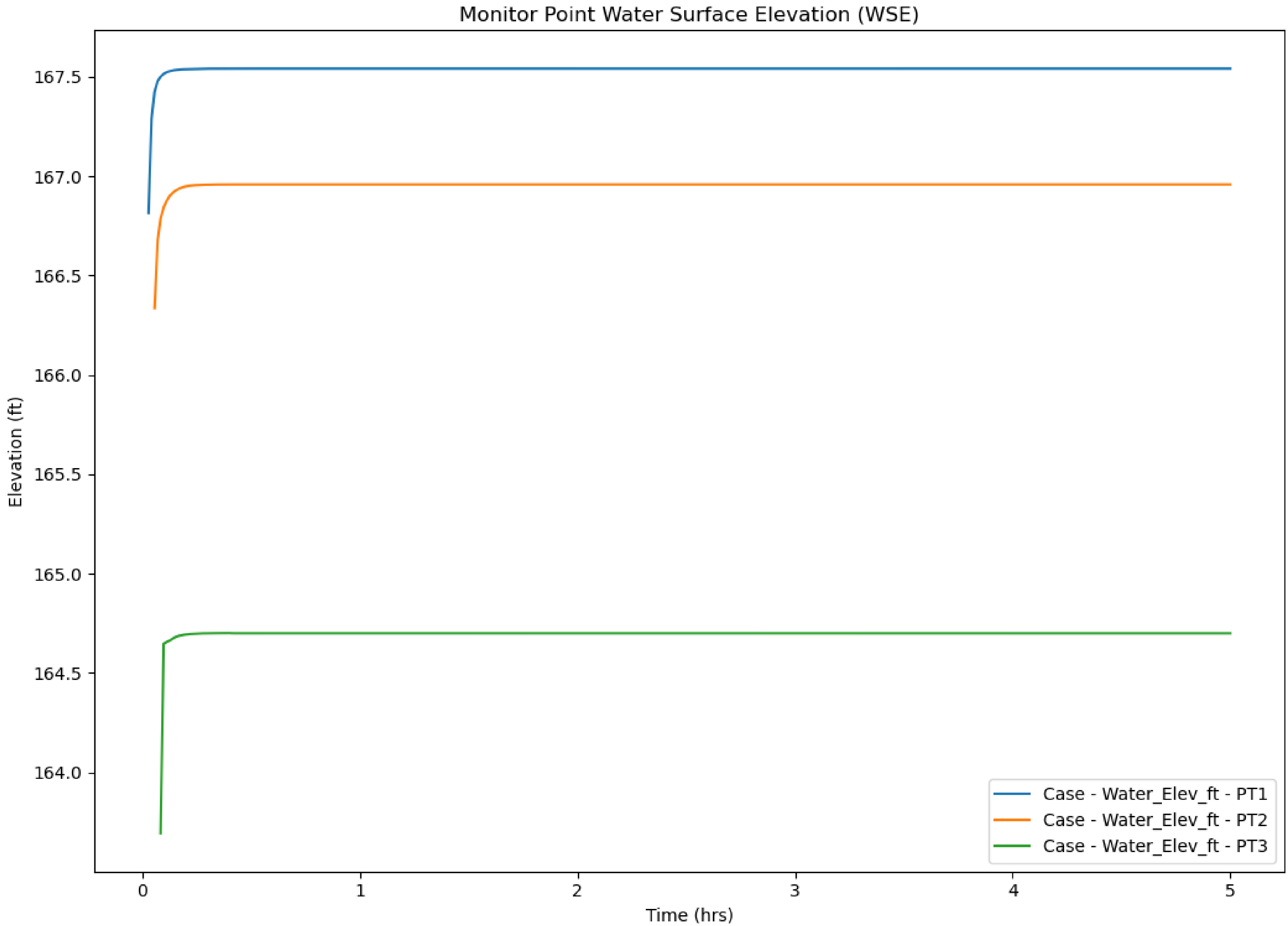


Figure I.9: Existing conditions 500-year monitor points

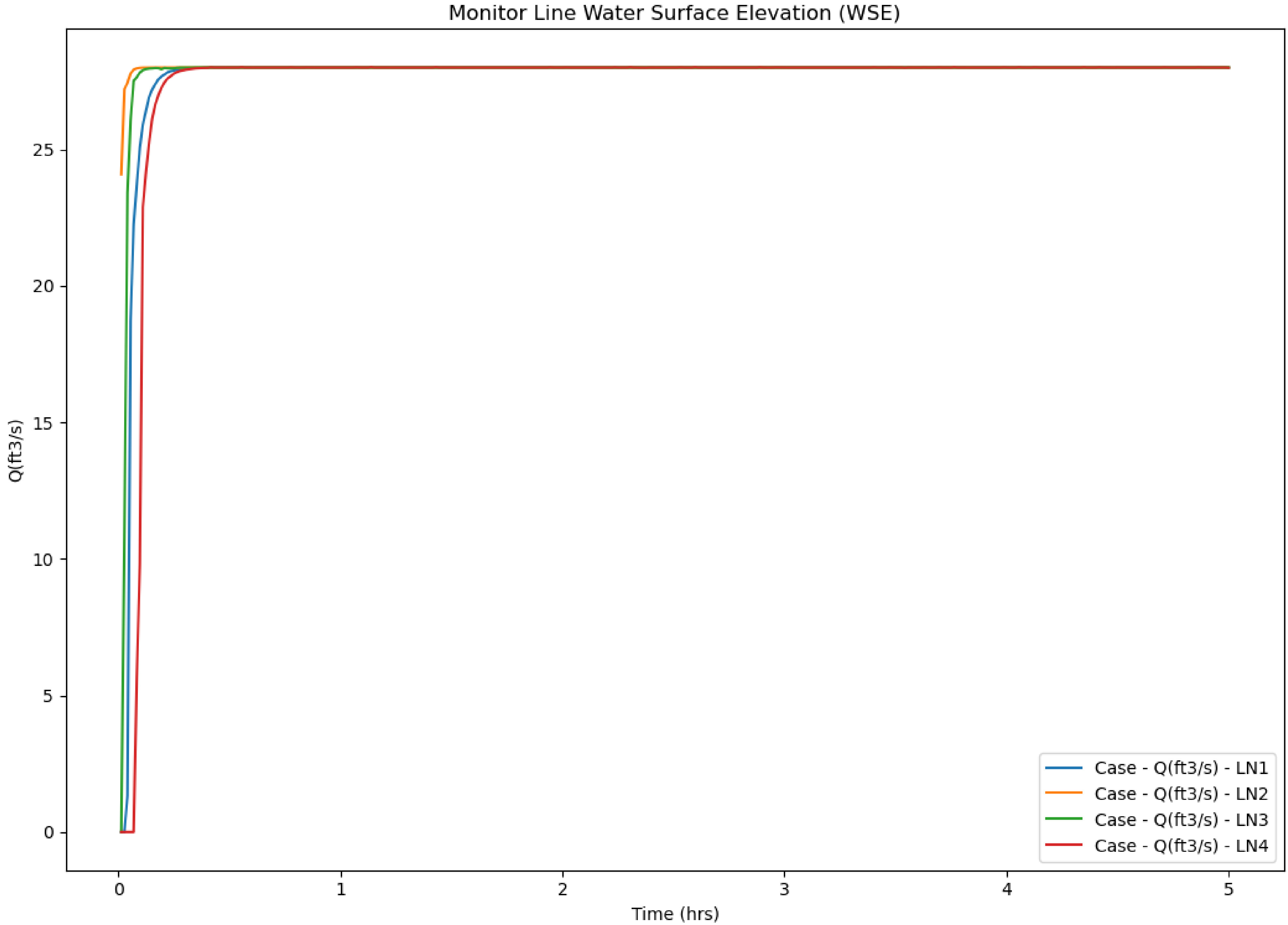


Figure I.10: Natural conditions 2-year monitor lines

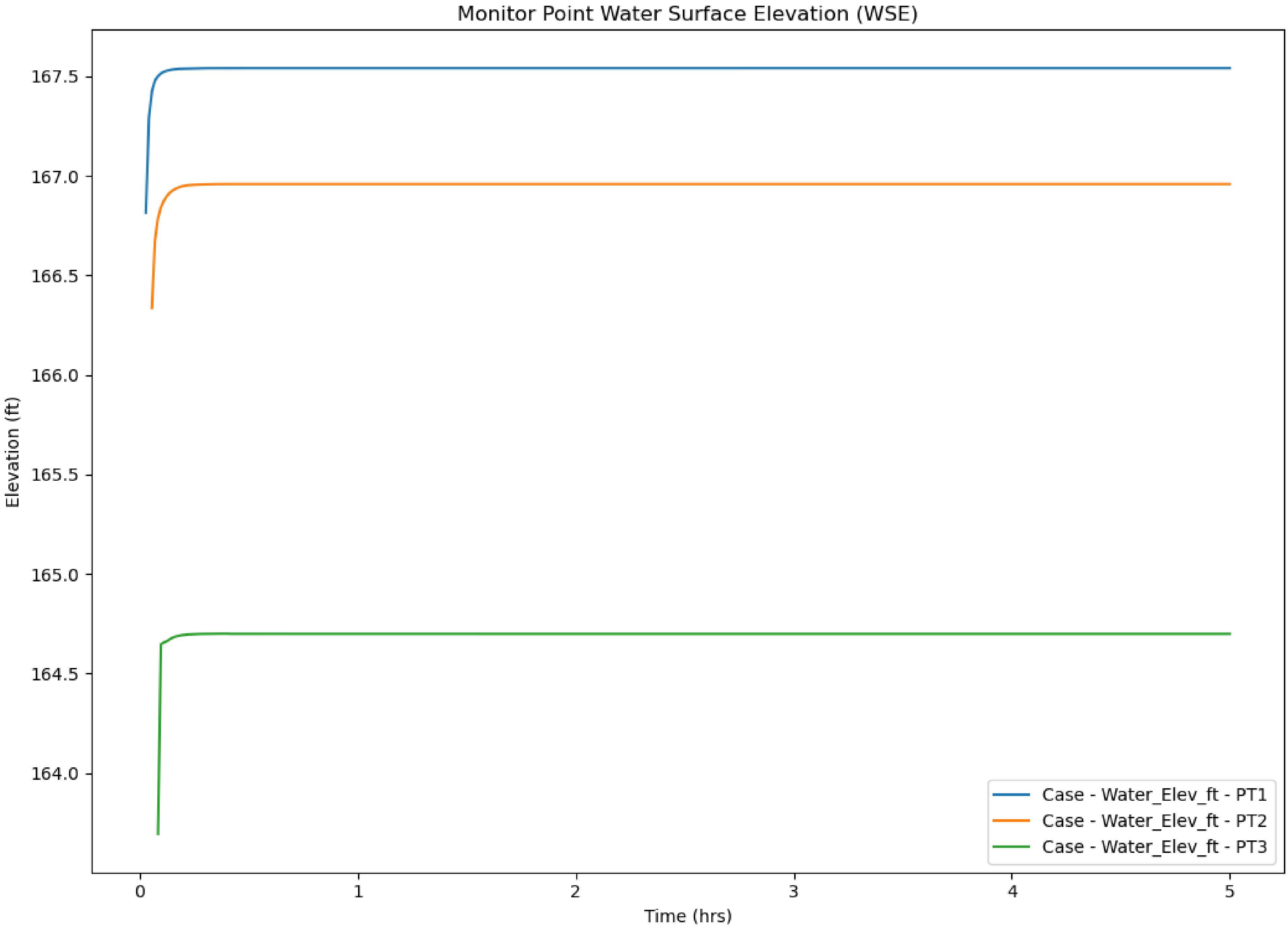


Figure I.11: Natural conditions 2-year monitor points

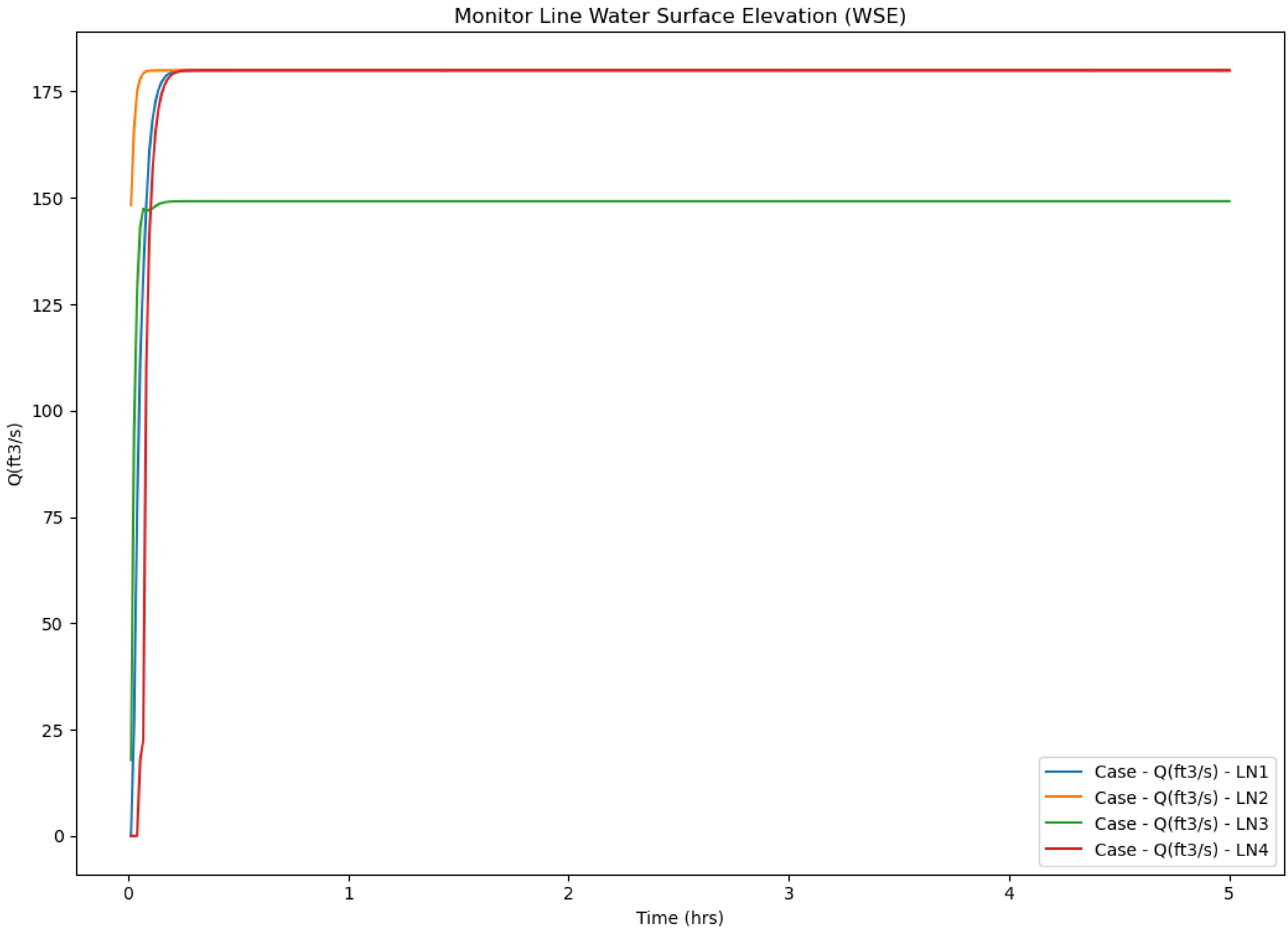


Figure I.12: Natural conditions 100-year monitor lines

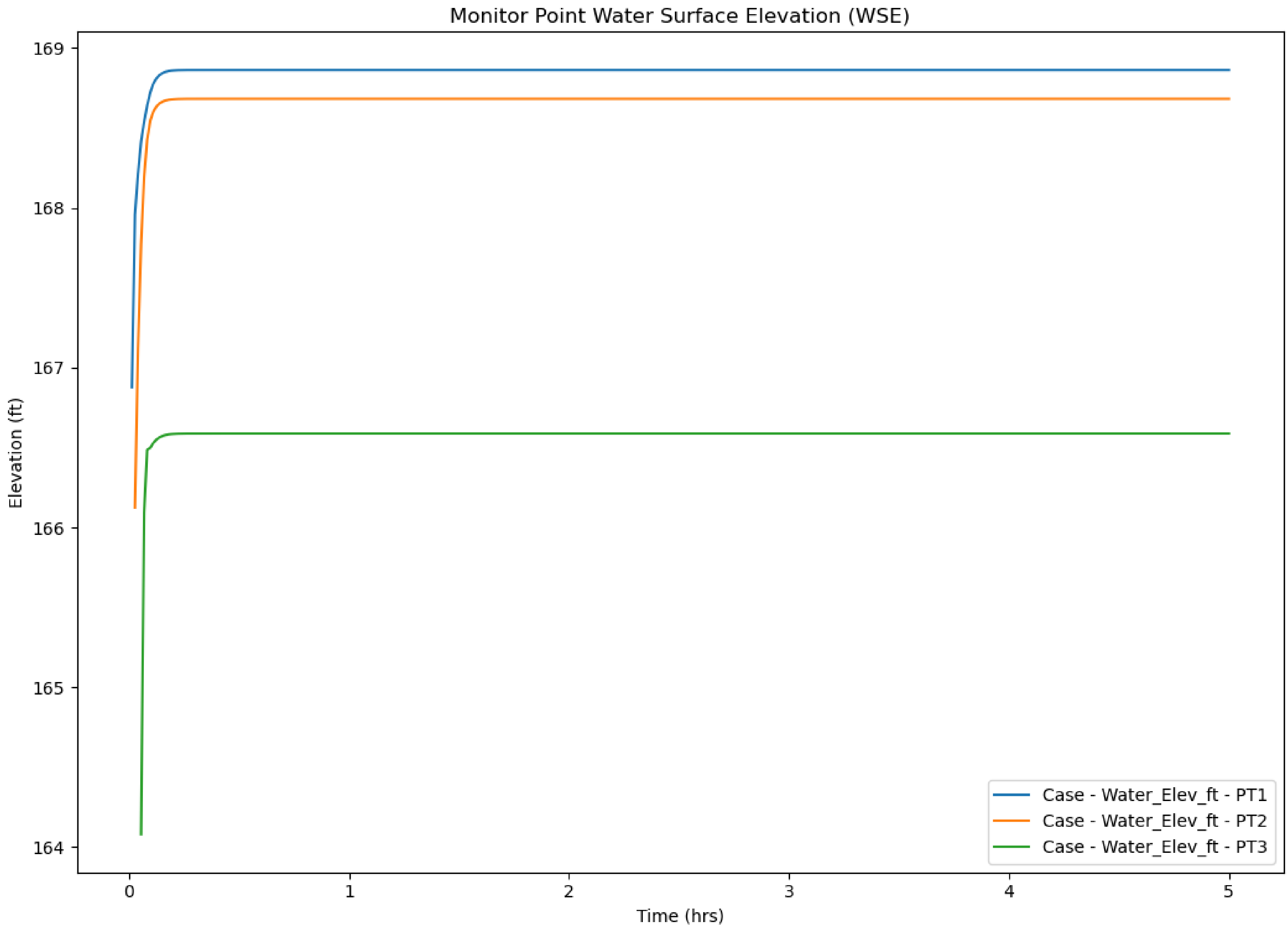


Figure I.13: Natural conditions 100-year monitor points

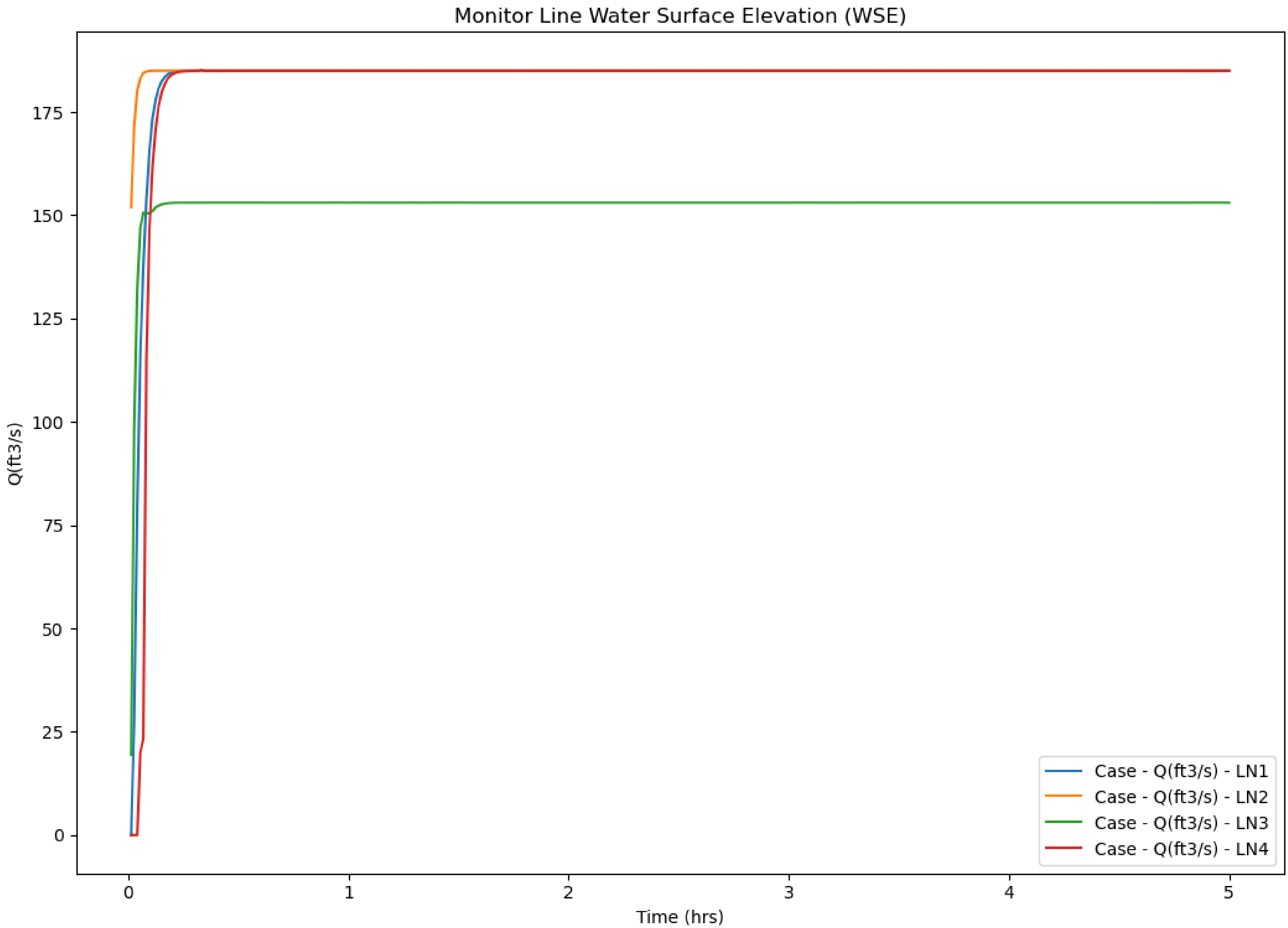


Figure I.14: Natural conditions 500-year monitor lines

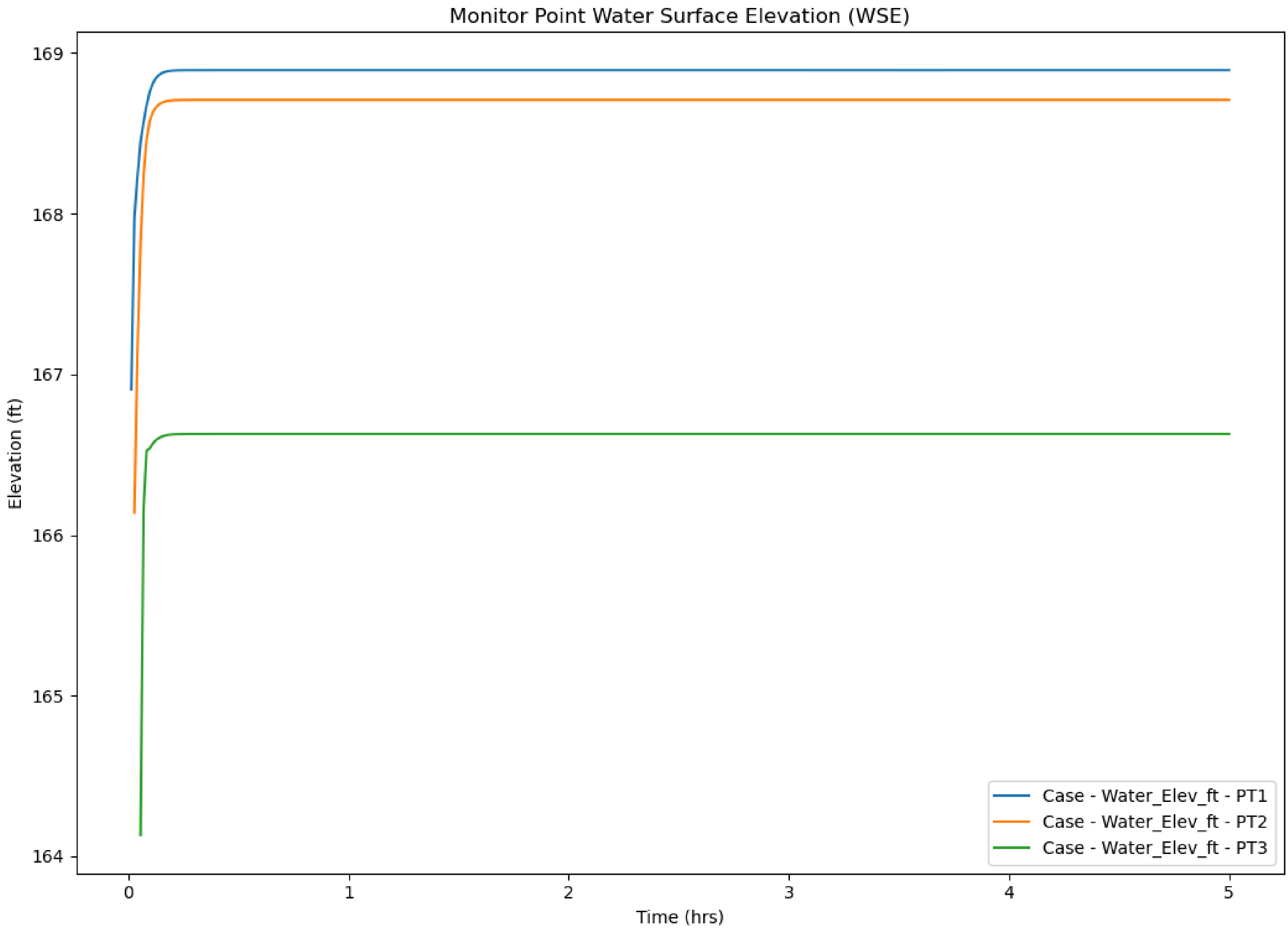


Figure I.15: Natural conditions 500-year monitor points

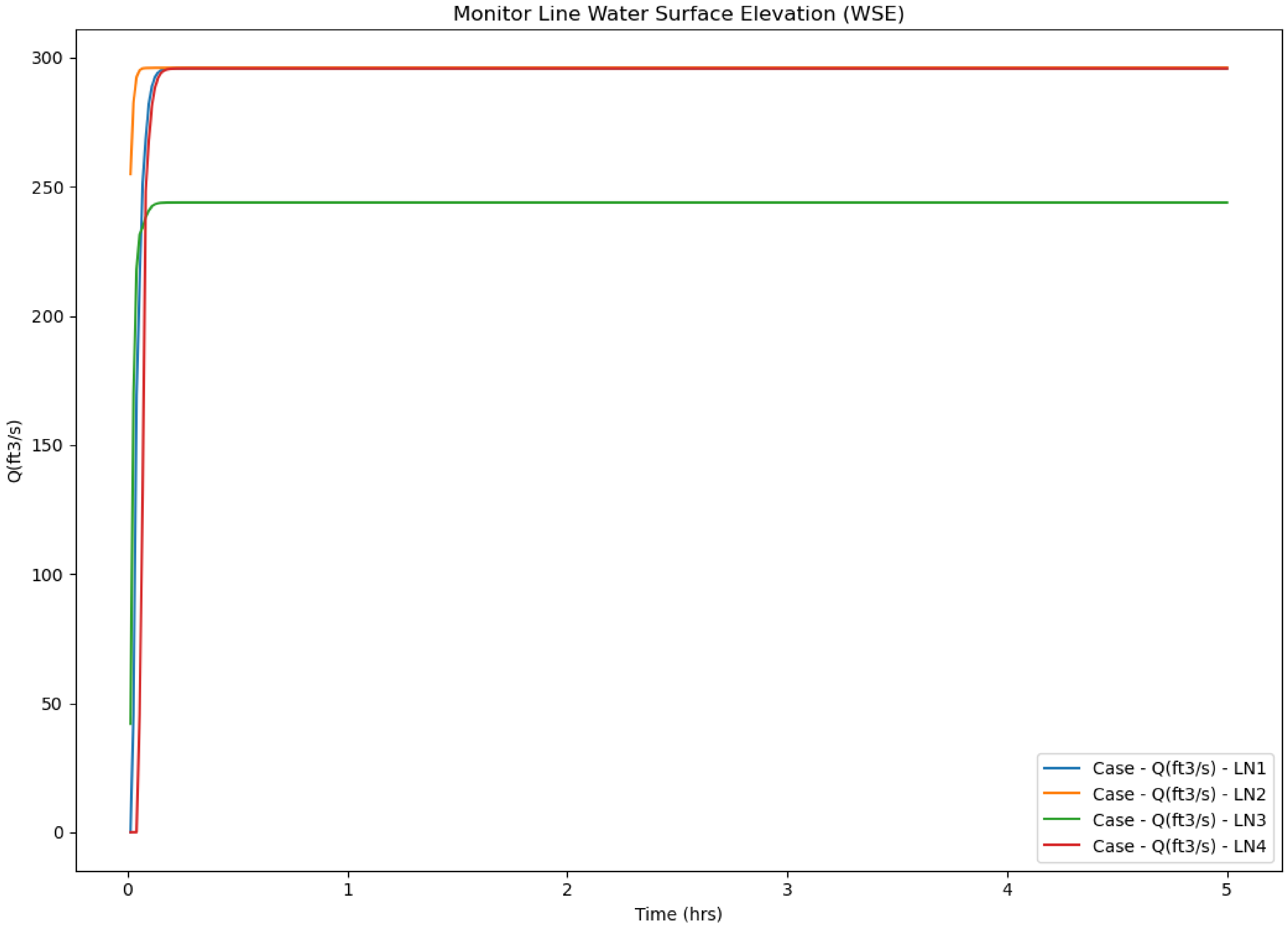


Figure I.16: Natural conditions 2080 projected 100-year monitor lines

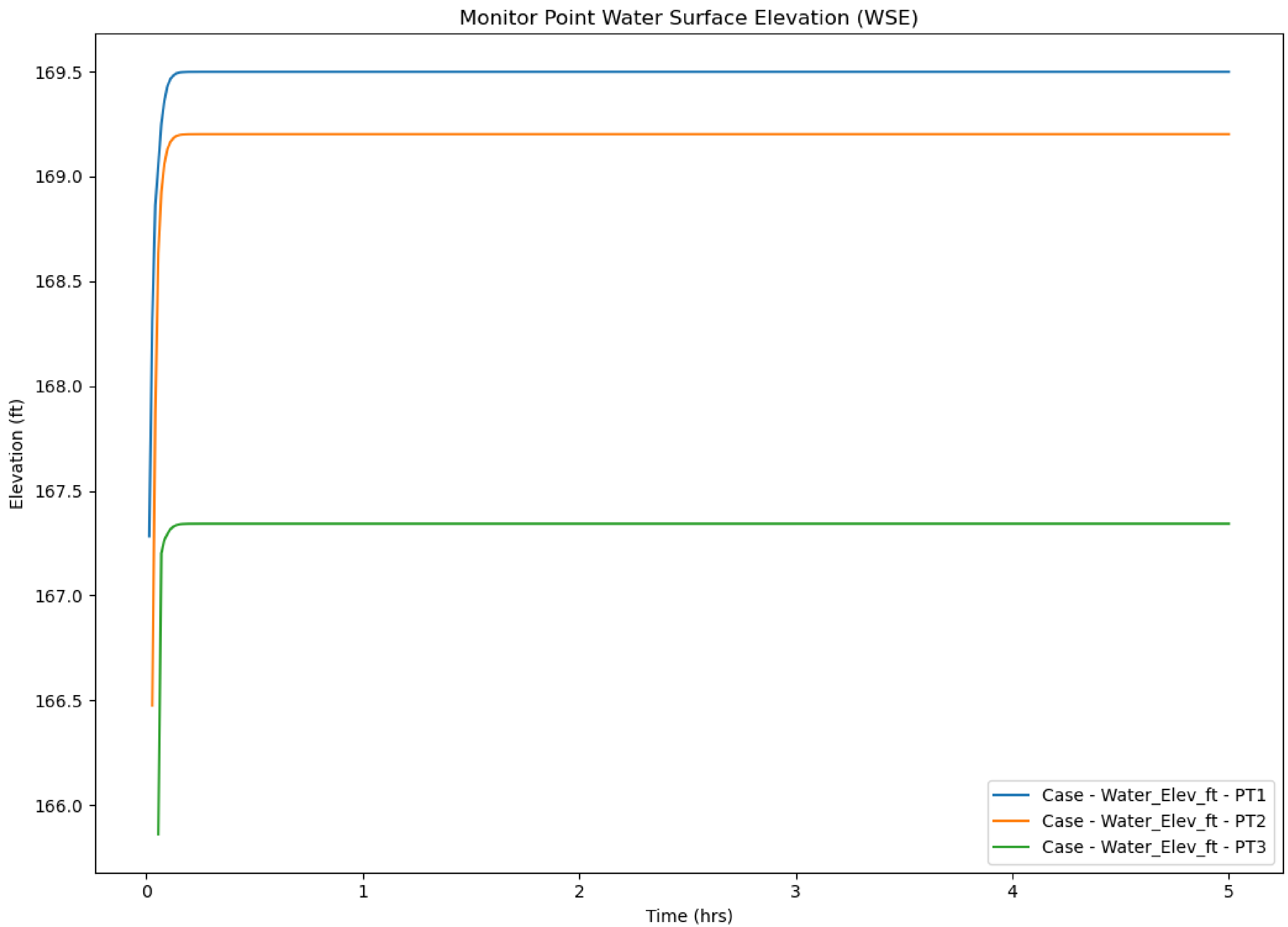


Figure I.17: Natural conditions 2080 projected 100-year monitor points

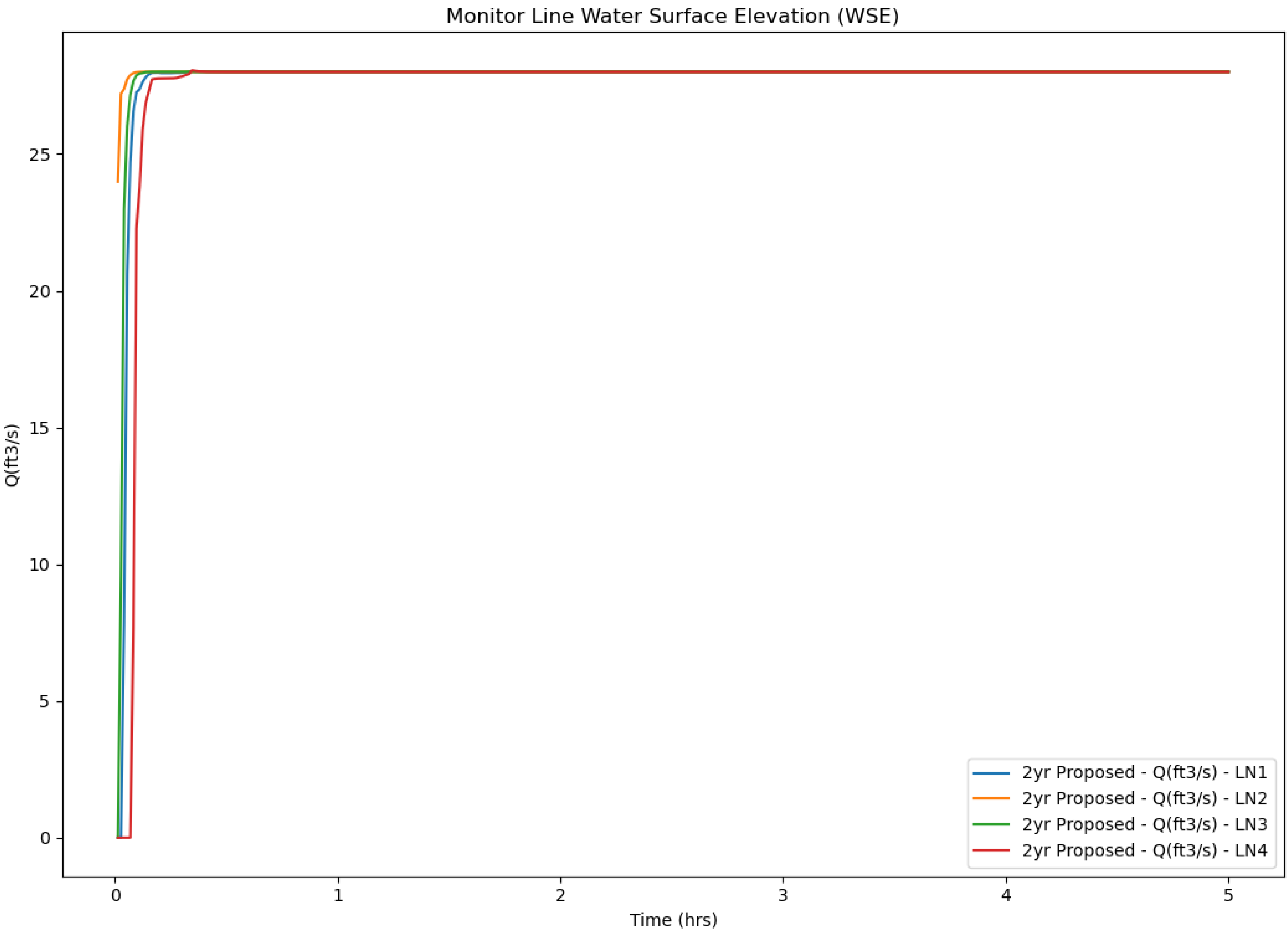


Figure I.18: Proposed conditions 2-year monitor lines

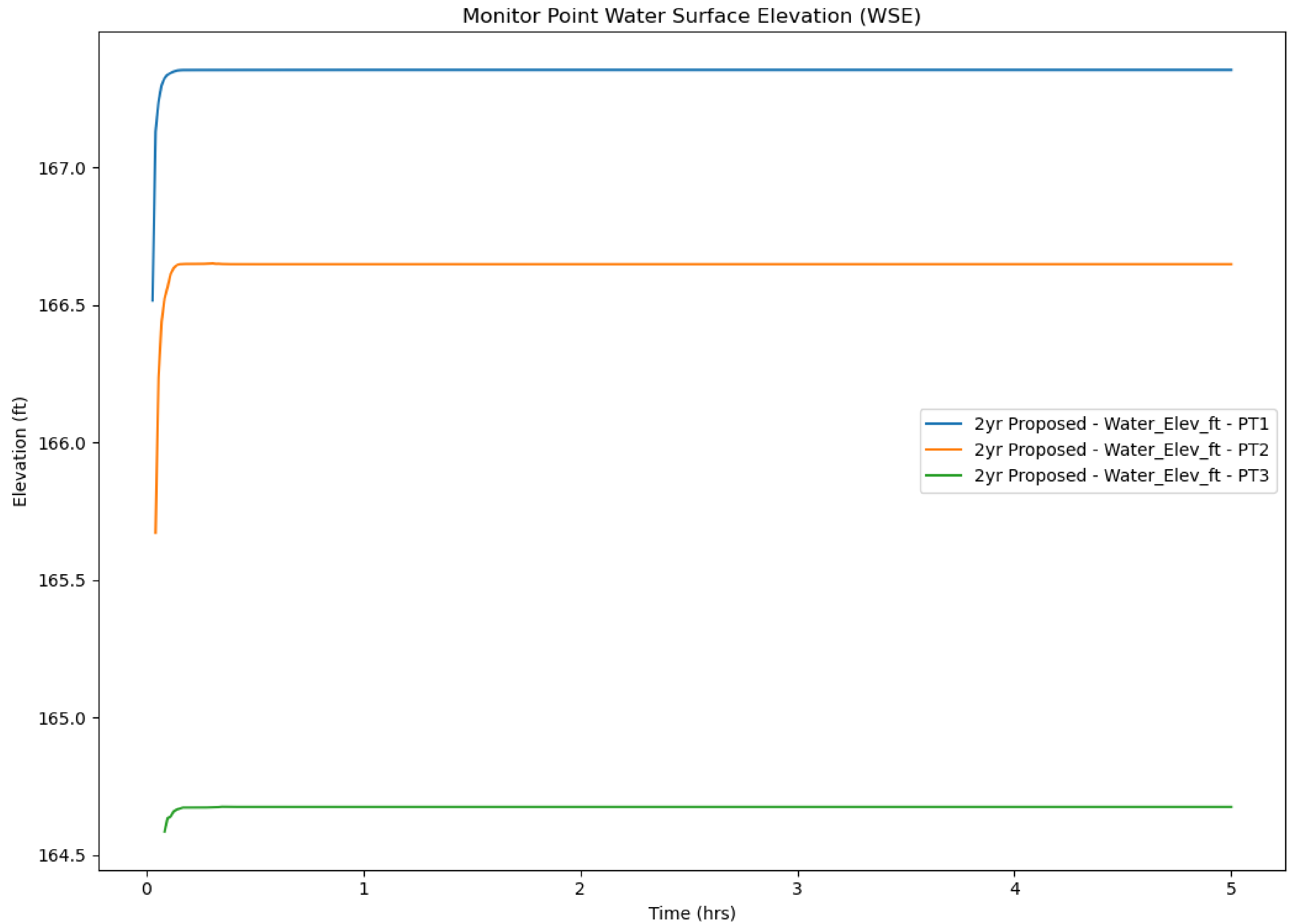


Figure I.19: Proposed conditions 2-year monitor points

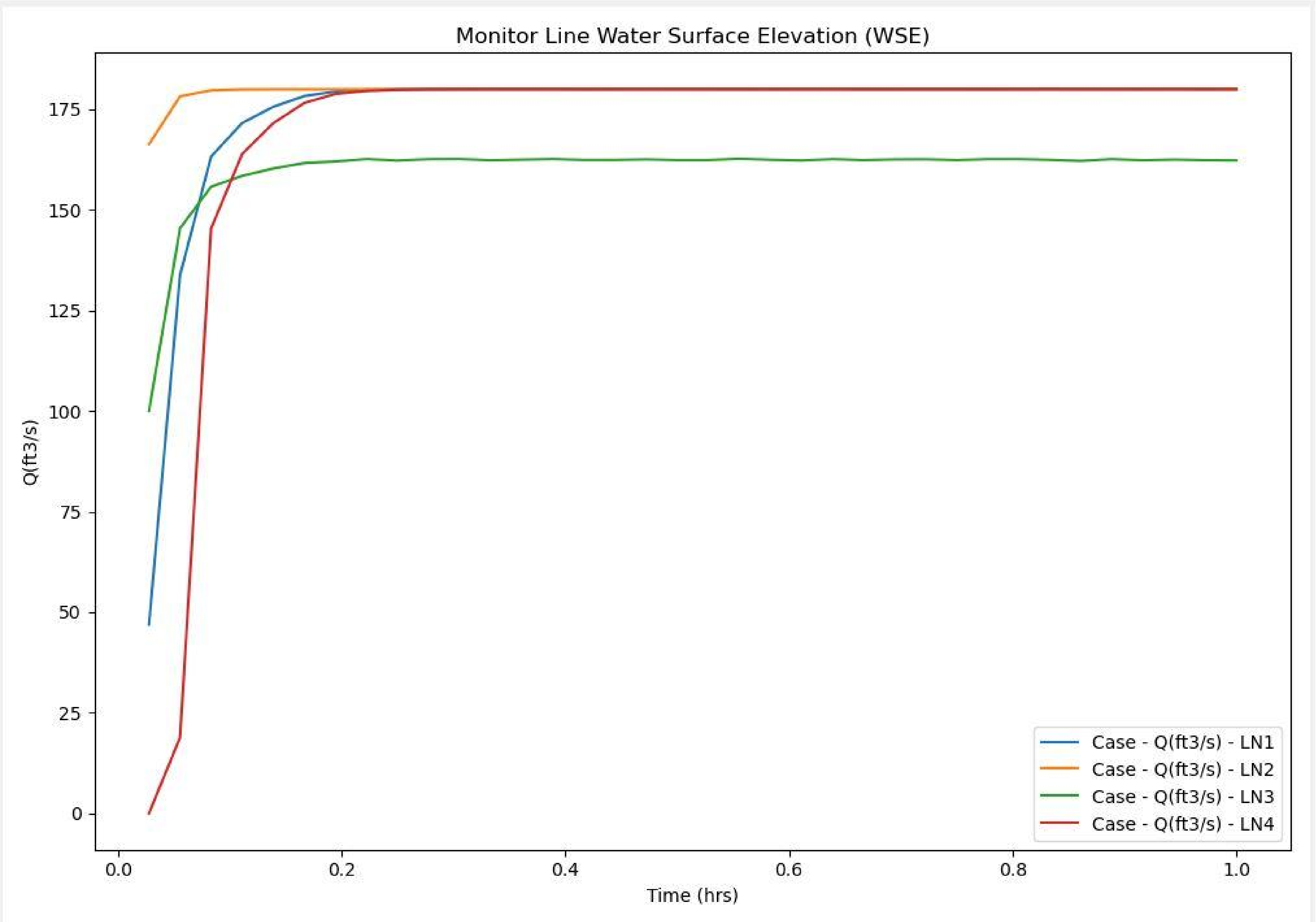


Figure I.20: Proposed conditions 100-year monitor lines

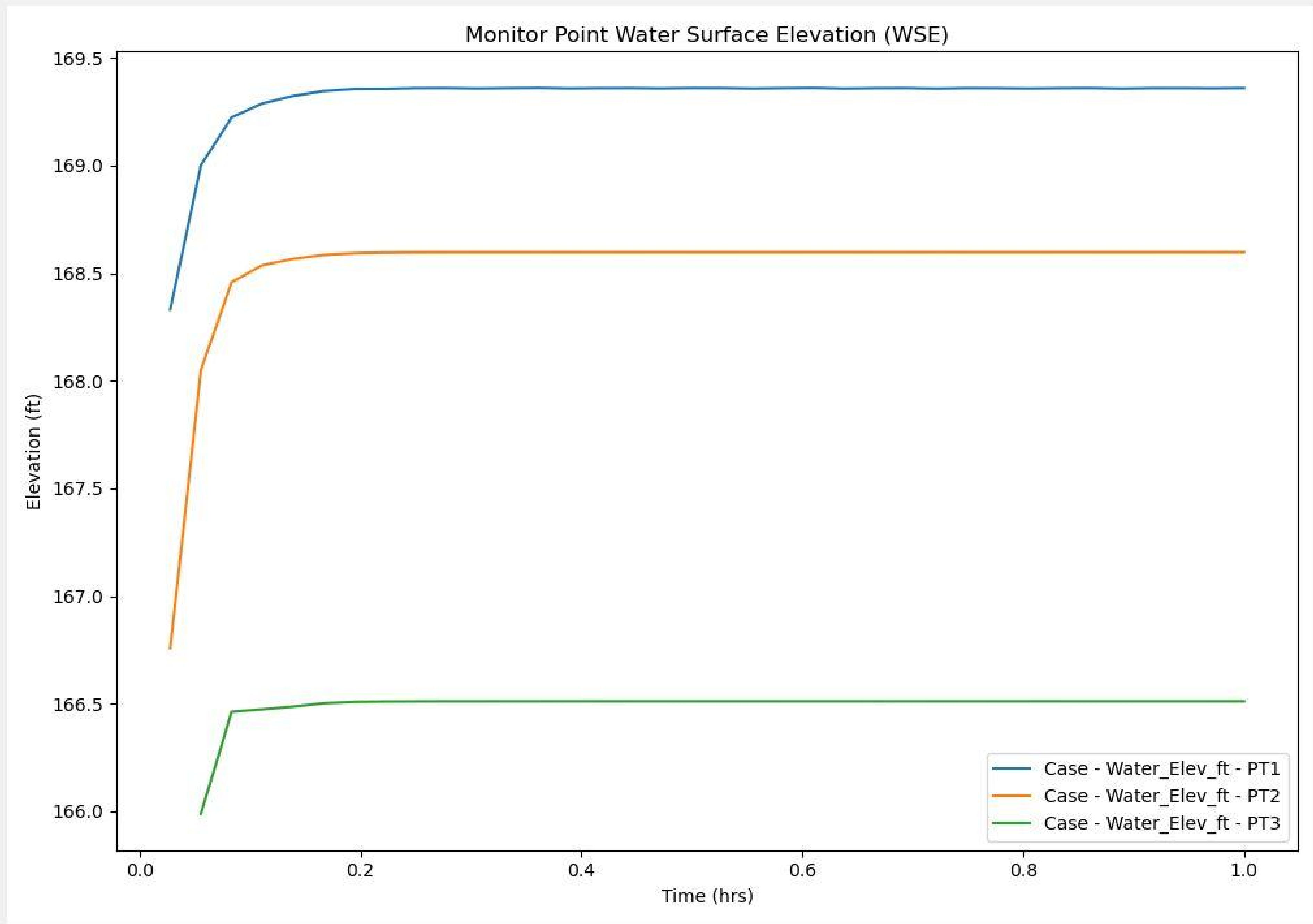


Figure I.21: Proposed conditions 100-year monitor points

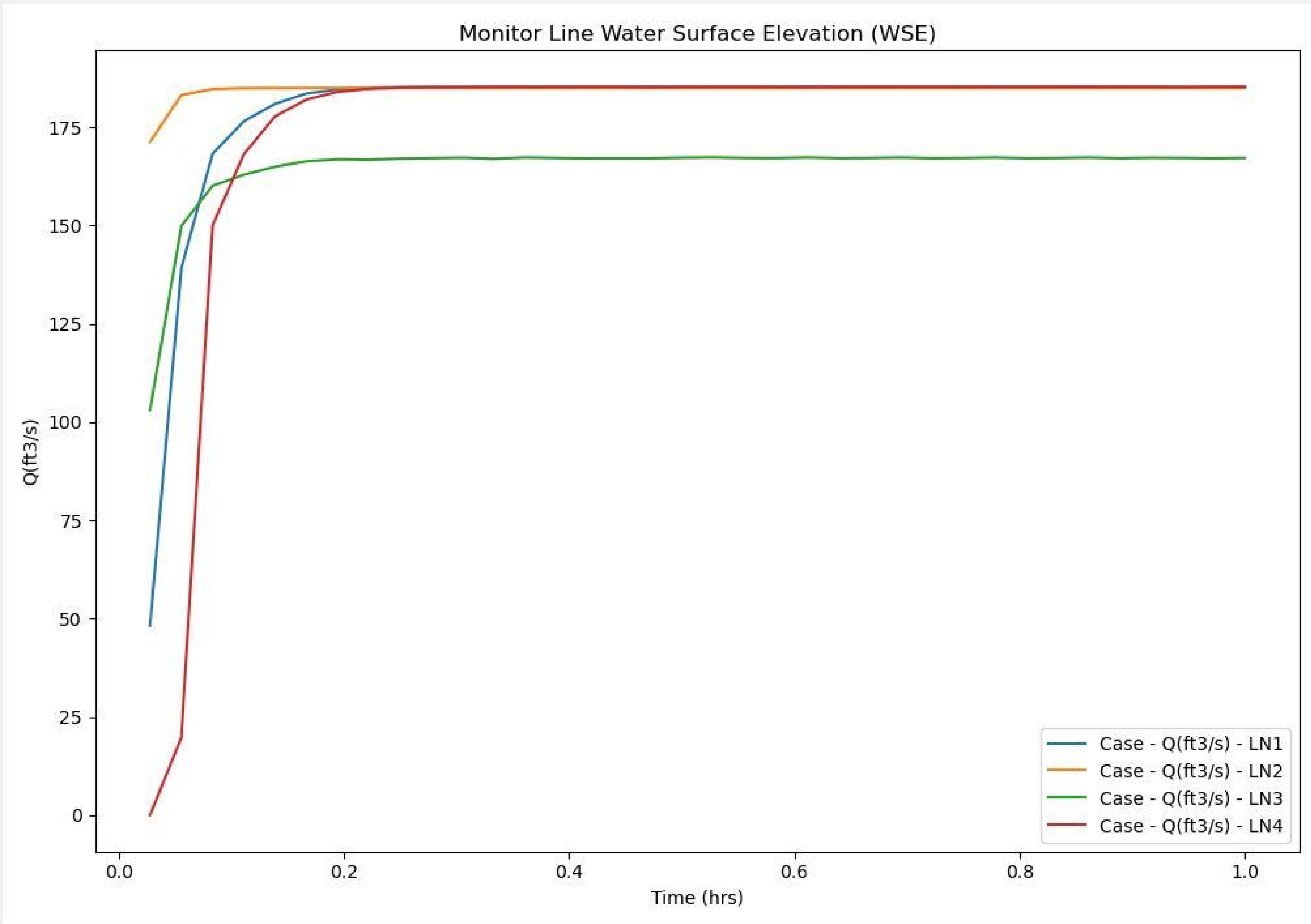


Figure I.22: Proposed conditions 500-year monitor lines

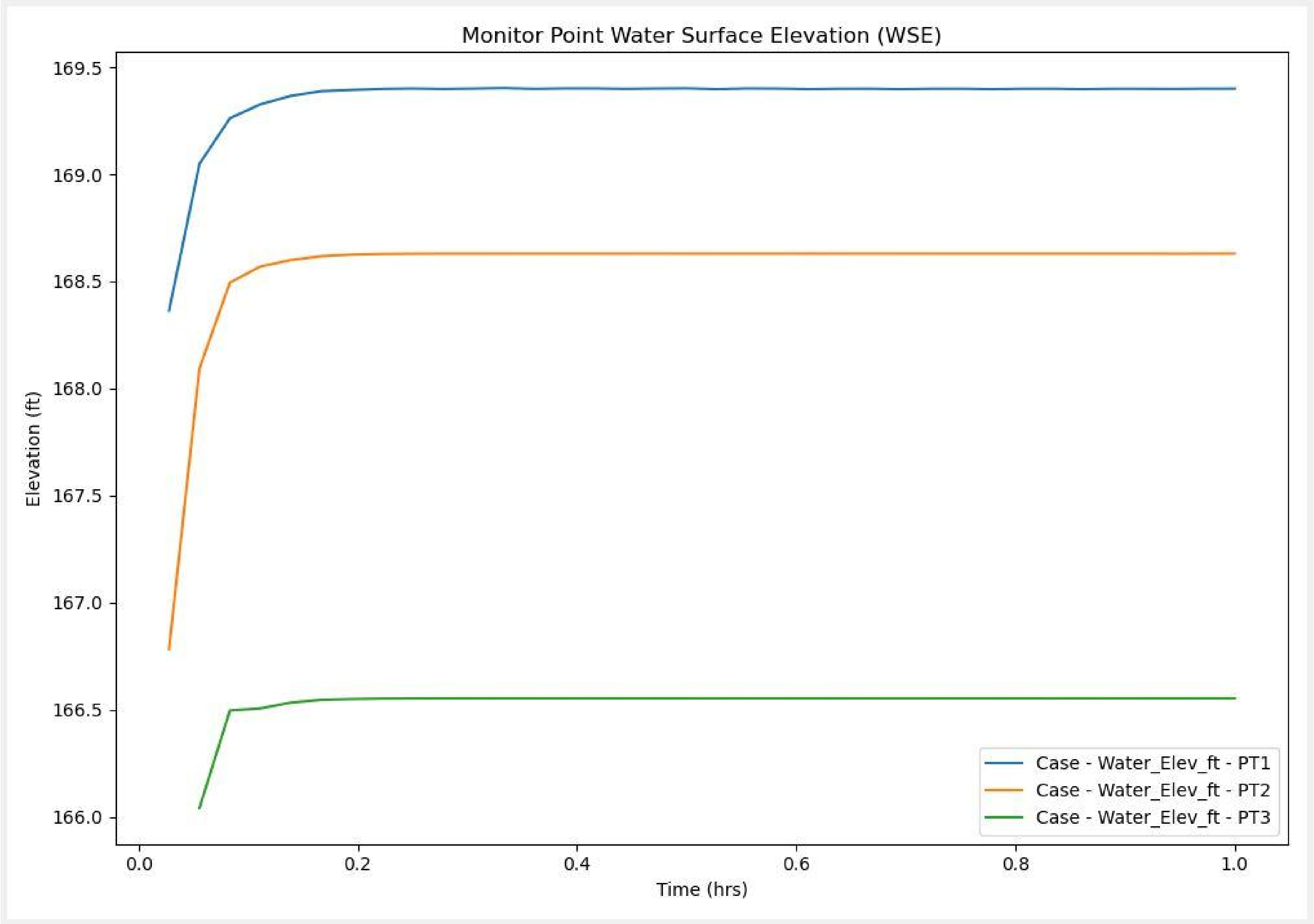


Figure I.23: Proposed conditions 500-year monitor points

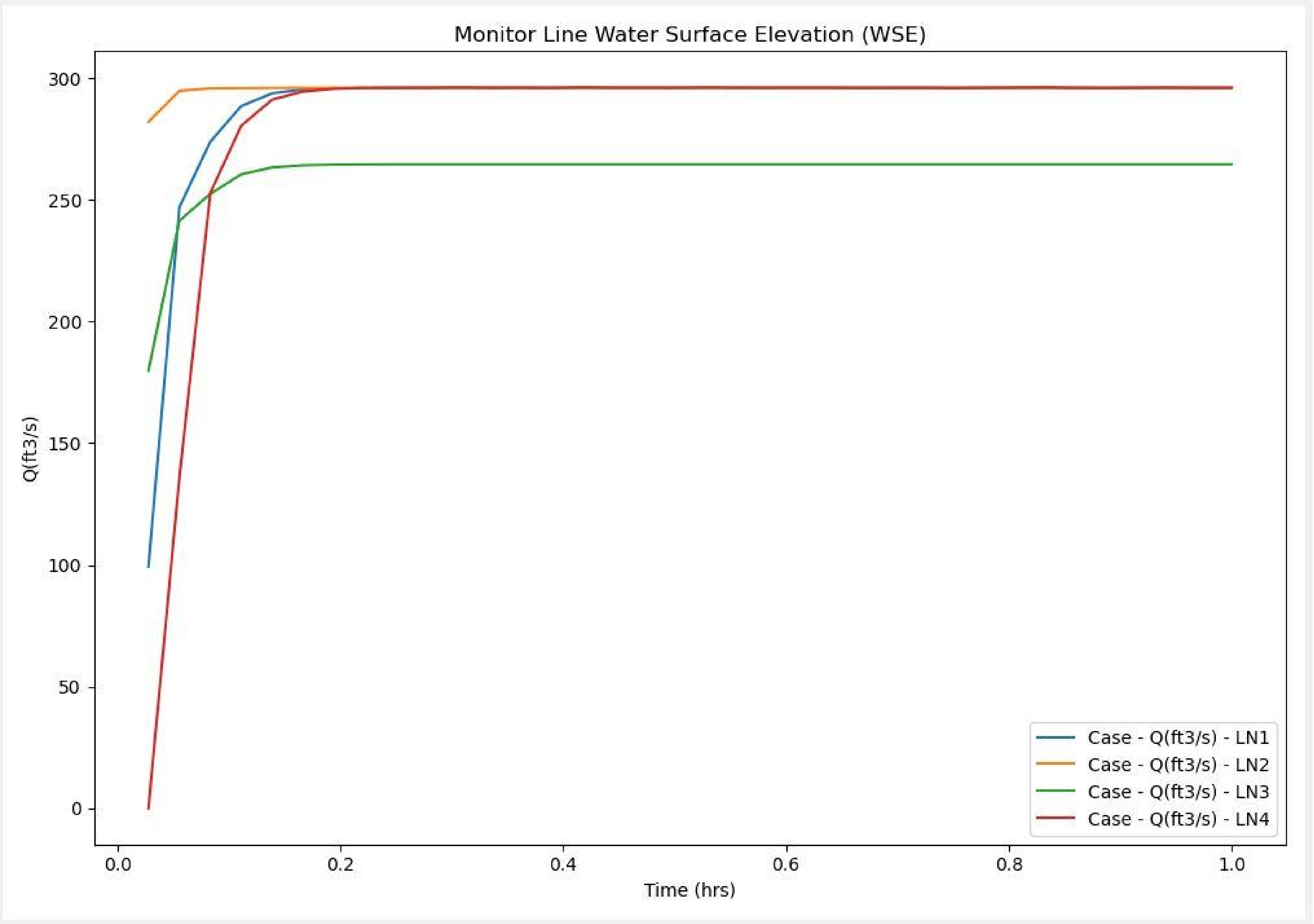


Figure I.24: Proposed conditions 2080 projected 100-year monitor lines

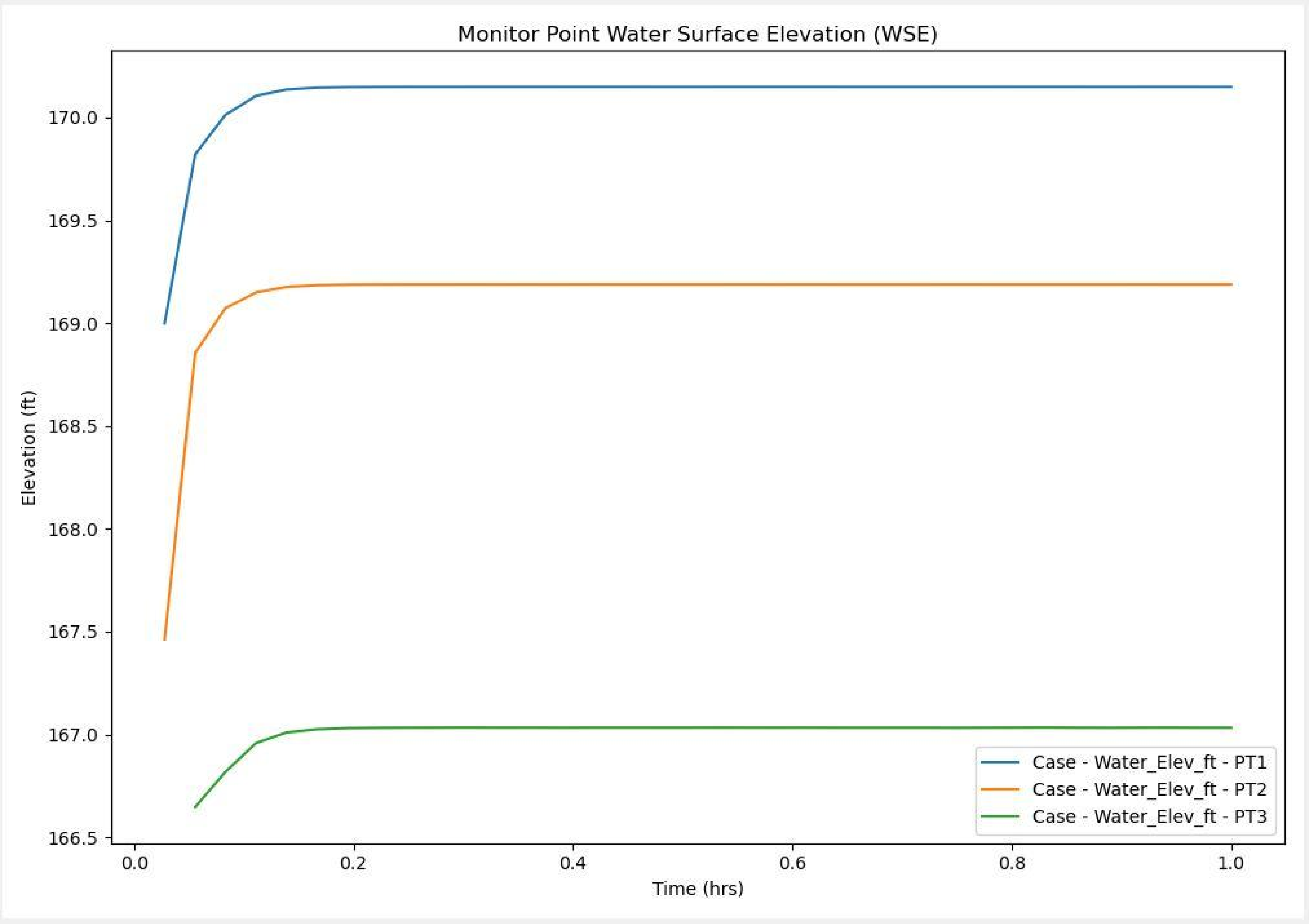


Figure I.25: Proposed conditions 2080 projected 100-year monitor points

Appendix J: Reach Assessment (NOT USED)

Appendix K: Preliminary Scour Calculations

This section is not ready for review at this time and will be provided with a future submittal.

Appendix L: Floodplain Analysis (FHD ONLY)

Appendix M: Scour Countermeasure Calculations (FHD ONLY)